Could light colour and source change mood in children with autism?

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DECLARATION OF ORIGINALITY

I, Nuria Hernandez-Rivera confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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ABSTRACT

Neuroarchitecture has shown in previous work that the environment and its features can influence, not only the mood but also the health and performance of its users. However, limited research has been done about the influence of environmental factors on the mood of people who suffer from sensory processing disorders and perceive the environment differently, for example, children with autism, using qualitative data.

Among all the possible architectonic features, the light was chosen as the matter of study after being considered as one of the most invasive and influential features of the environment that could impact the temper and behaviour of a person. This study aims to design a tool to measure the influence of the colour and source of the light has on the mood of children with autism to know which types of light might improve their well-being in the future.

Four children participated in a study in which three physiological signals (electrodermal activity, facial thermography and rate per minute of tics) were measured while they were playing with toys under different light conditions. Results showed that the different sources (LED and fluorescent light) and colours of the light (yellow, green, red and blue) could influence their physiological and behavioural responses. The data obtained in the experiment was introduced in an innovative three-dimensional system called '3D Mood Box' to identify the emotional states of the participants and thus, for instance, their mood, and results showed that the different types of light affect every child differently.

Information extracted from this tool will inform future design decisions which can improve the mood of the participants. This thesis also raises awareness about the influence of architecture in the well-being of all the users, especially those who perceive the world differently. Moreover, the method proposed can be applied in future research in order to understand the reactions of any individual towards the environment.

Keywords: Sensory processing disorders, autism, light, colour perception, mood, neuroarchitecture, architecture.

IMPACT STATEMENT

Impacts deriving from this study can be local, national and global scale, affecting many groups with incremental benefits over decades. The main academic and non-academic beneficiaries of this study are subdivided into researchers, architects and occupational therapists.

On the one hand, the methodology followed, and the innovative tool called '3D Mood Box' presented in this thesis will help researchers to understand the mood of an individual when interacting with the environment. The method only used objective data obtained with non-invasive equipment. Although the method was used to study the influence of light in children with autism, it can also be used to study the influence of any factor of the environment that affect the welfare of an individual. The information obtained can increase the knowledge about the individual and their sensory needs so architects and researchers can design friendly and efficient environments which would suit better the needs of the individual.

This method also informs researchers about physiological and behavioural data that can be enlightening to comprehend the impact of the light on the mood of children with autism. Both the colour and the source of the light have an essential influence on skin conductance, the temperature of the tip of the nose and rate per minute of tics; and also impact on the mood of the individuals by making them feel more relaxed, excited, sad or stressed under different light conditions. The results could be used to alter the environment and, hopefully, improve the mood of the participants in the academic and work environment and home when necessary.

This study encourages translational research and collaboration between researchers and architects, so the new knowledge is implemented in the professional practice to improve the quality of the environment and quality of life of those who experience it.

On the other hand, the study can also serve therapists to understand better the mechanisms behind every reaction and strengthen the idea that the environment can have an essential role in provoking the reactions. Therefore, this study can offer constructive ideas to adopt informed decisions when designing or adapting the environment for children with autism by using different lighting ambiences, so it can help to improve the quality of life of the students.

Finally, the findings reinforced the idea that even though the children belong to the same collective of population, the light affected the mood of the participants very differently. Therefore, this study will benefit society by raising social awareness among academics, architects and researchers about the vital influence that the environment has on the individual, and the importance of thinking about the particularities of individuals when designing spaces for them, who deserve a proper approach to satisfy their needs and enjoy the most beneficial experience. The ultimate beneficiary of this study is the general public who will benefit from new environments which take into consideration their well-being and sensory needs to improve their performance, mood and health, that is their quality of life.

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CHAPTER ONE – INTRODUCTION

People perceive the environment through their senses. The different senses operate as tools to gather information about the environment and send this information to the brain to interpret these signals. Both psychological and biological reactions are the result of this interpretation, so our body can react to the stimuli in many different ways. Thus the different components of the natural and built environment can induce different outcomes that can be positive or negative for us. The environment has the power to change our mood, improve or worsen our productivity and impact on our health, among others (Salingaros, 2017).

Since the age of Vitruvius, architecture has evolved to respond to the needs of the population. However, does architecture satisfy everybody's needs?

People with sensory processing disorders, such as people with autism, perceive the environment in a very different way and these different processes mean that the relationship between these individuals and the environment might be stressful (Dilascio, 2014). The increasing knowledge about neuronal differences between people with autism and neuro-typicals (Baron-Cohen, 2000) suggests that design solutions broadly accepted through the years by the majority of the population seem to incite health issues, extreme behavioural alterations, aggressive behaviour, and even isolation among individuals with autism. In other words, the environment might be uncomfortable or even threatening (Dilascio, 2014), for people with sensory processing disorders, and new design solutions need to be considered.

Architecture needs to be sensory-accessible. However, how can architects really understand what people with autism require?

From the early twenty-first century, neuroscientists and architects joined forces to understand how the different stimuli could affect the behaviour, health and well-being of the population with different empathetic tools, so architects and designers could use this information to obtain the best outcomes from the relationship between the environment and the brain of every human being. This relationship gave birth to the approach called Neuroarchitecture.

Two of the most universal components present in all our experiences with the environment are colour and light. They are omnipresent. They are present in nature and have to be designed in the built environment. According to different studies presented in Chapter Two, both have proven to be factor that could severly influence the physiological signals (i.e. Gerard, 1958; Jacobs K. W. & Hurstmyer, 1974; Wilson, 1966) and behaviour or cognitive performance of a person (i.e. Soldat et al. 1997).Therefore, light and colour of the light, and their intrinsic characteristics, can induce different outcomes in health, performance and mood.

Even though there is evidence about the neuronal differences between people with autism and neurotypical people, and about how these differences can impact on the perception of the environment, no research has come to light about how the colour of the light can affect the mood of individuals with autism, although colour and light are two ubiquitous components of the environment that could severely affect many different aspects of our psychology and biology. Anecdotal evidence about fluorescent light suggests that the flicker and buzz from the light source might cause health issues such as migraines, aggressive behaviour and epileptic seizures in children with autism (Grandin, 1996). Instead of fluorescent light, the use of Light Emitting Diodes (LED) as a light source is often recommended as a possible solution, but so far, very little research has been carried out about the different impact provoked by LED lights on the mood of children with autism.

The powerful influence of light revealed in the literature suggests that proper lighting design solutions could improve the injurious relationship between the environment and people with severe autism. These design solutions could not only transform this relationship into a less stressful experience but could also help to obtain favourable outcomes from it.

For these reasons, and after detecting this gap in the literature, this research focuses on **developing a method and designing a tool to inform how the source and colour of the light influence children with autism's emotional responses**.

Hopefully, if researchers and architects know how the colour and source of the light impact on children with autism, light could be used to adapt the environment and improve their mood, their behaviour and academic performance when needed, and ultimately improve their quality of life. Unfortunately, as often children with autism cannot express their reactions and emotions by themselves, it has been observed in different schools like Prior's Court School that they show their discomfort and frustration with the environment through health issues, tantrums, self-injurious behaviour and isolation from others.

To know how the colour and the source of the light influence children with autism's mood without using their testimonies, it is suggested to perform research that informs first about how the light impacts on their physiological signals and behaviour. The information thus obtained could be combined, so the mood under different light conditions can be interpreted.

As this is likely to be one of the first studies studying the mood of children with autism under different light conditions by analysing their physiological reactions, many questions about the methodology are addressed throughout this thesis. It is important to stress *a priori* that one of the characteristics of autism is that no two people with autism have the same responses to environmental, or any other, stimuli. Each person with autism has to be assessed individually to see how they respond to the world in general and specific stimuli in particular. There is no general rule for these responses, only insofar as each person will have a response to something: the question is, therefore, to find out what the responses are for a specific person when confronted with a particular stimulus.

As children with autism can be extremely overwhelmed by new events and unknown circumstances, the methods employed by the research will need to adapt to their individual needs, making sure that the children would not be stressed beforehand by the processes involved in the collection of the physiological and behavioural data. That means that it is necessary to pay special attention to the location of the experiments, the protocol and the devices used.

As no two children with autism are the same, the research reported in this thesis is not about shedding light about the autistic condition itself, but instead, it is concerned with a new tool that can measure and identify how a child affected with severe autism copes with different sources and colours of the light in their immediate environment, how these stimuli can influence their daily life, and how the results obtained in this study could be used in the future to help them cope with the challenging experience of interacting with the world. To ensure that the method is not specific to only one child, a group of four children, each with severe autism but displaying different characteristics of the condition, are studied in this study. This study will also show how the methodology needs to adapt to the peculiarities of each participant yet can provide some consistent indication of the influence that the light might have in each case.

The scope of this research is to create a tool and a method that is sufficiently flexible to work with each of these four children and to provide some insights into their reactions to different lighting conditions. Although in creating such a method, it might be possible to consider how it might be possible to open it up to the needs of other children with autism, the intention is to gain a specific understanding of how to explore these issues with these particular children. It is, therefore, possible that the general approach of the method might be generalisable, and there will be a discussion on this point, but that the details of its application to different stimuli, or different children, are beyond the scope of this thesis.

1.1. Thesis objectives

Hence the predominant question of this study is:

Can a tool be designed to evaluate whether external stimuli from the environment such as the colour and source of the light affect the emotional responses of a child with autism?

This question can be broken down to the following sub-questions:

1. How can the influence of the colour and source of the light in children with autism be quantified?

   As no previous research about measuring the influence of the colour and source of the light in the mood of children with autism using only physiological and behavioural analysis has come to light to the author's knowledge, the ground-breaking feature of this study begins from the choice of physiological and behavioural data, and the equipment to collect them, that can provide information about different aspects of the emotional state of the participant.

2. How can the mood of children with autism be identified and quantified without using subjective tools?

   Self-report questionnaires are tools broadly used among psychologists to determine the mood of participants. However, children with severe autism have limited language and communication skills, and their condition ruled them out from the possibility of answering subjective, complex or abstract questions about their mood. For this reason, this study can only rely on objective data. While physiological and behavioural data can be misleading when analysed in isolation, the combination of adequately selected physiological and behavioural data should be able to provide information about the mood of the participants under different light conditions.

3. How should the sessions of the experiment be designed to gather relevant information effectively that will help to interpret the influence of the colour and source of the light on a child with severe autism?

One of the primary challenges of this study will be the nature of the participants. Children with severe autism might easily become stressed when they have to deal with unknown events that involve unexpected circumstances, especially without a previous warning (such as the sudden change of the colour of the light). They need specific care to engage with the activities and the researchers long enough to show their body responses for a while. Children with autism might be less constant and consistent throughout the sessions compared to other people, and they can be more likely to interrupt the study for medical issues. For these reasons, the method, while being objective by nature, needs to be flexible to many possible scenarios during the data collection process, and to bear in mind all the possible triggers of anxiety. The method needs to try to avoid these triggers and to rely on exhaustive analysis of the data and its variants concerning the unique nature of each child as an individual. As a result, as each child is different, the issue is to understand what the data reveal about each child: a projection of this outcome onto a larger population through statistical analysis would have no meaning. In this research, in order to ascertain if the method might be able to work with more than one child, it is used with four children with severe autism. This enables the individuality of each child to be incorporated in the analysis, and the method is then explored in terms of its ability to cope with the differences between these four children.

4. How many different lights need to be studied to evaluate the validity of the method to observe differences in the emotional responses of children with severe autism under different light conditions?

The colour of light can be determined by its different characteristics of hue, saturation and intensity, among others, which will be explained during this thesis (Chapter Two). These properties can be controlled easily in LED systems, and the combinations can be endless. Although any of characteristics can be a determinant of the impact that the light has on the participant, only the hue will be varied, maintaining saturation and intensity the same during all the sessions so the light conditions are limited and can be repeated in search of consistency of the results. To give a broad representation of different light wavelengths in the research, four colours (blue, green, yellow, red) and two sources of ‘white’ light (fluorescent and LED) will be tested.

1.2. Thesis structure

Chapter One is introductory and explains the justification, objectives and the structure of the thesis.

Chapter Two provides the background of the research. It starts introducing the approach called Neuroarchitecture and emphasising the idea of the functionality of the architecture and its physiological influence on the individual who experiences it. The literature review shows different architectural factors that can impact on the physiological signals, performance and mood of the individual, and finally focuses on the impact of colour and light has on different aspects of the daily life of the people in general. After reviewing different studies which have examined the influence of the light on mood and behaviour, the research question is raised of how the light could influence people with Sensory Processing Disorders, such as people with autism, whose perception of the environment differs from the neurotypical perception in many aspects.

Chapter Three sets out the methodology to be followed in the research to answer the research question about developing a tool to understand the influence of the influence of the colour and source of the light in the mood and the reactions of a child with severe autism. This chapter includes the criteria followed to recruit the participants, the description of the environment where the case study took place, a description of the lighting system designed for the purpose and used, the types of lights examined and its properties, the equipment used to record the physiological signals and behaviour of the participants, the light sequences examined, and the possible tasks the participants were doing during the sessions. This chapter also explains why baseline tests and control groups were not necessary for this case study.

Chapter Four describes the steps followed to develop the database and explains how the data was collected and analysed. The database will be composed of qualitative data about the participants, physiological measurements of the participants, such as the electrodermal activity and thermography, and behavioural responses under different light conditions.

Chapter Five presents the results obtained from each participant about electrodermal activity, thermography and repetitive behaviour, shown first, by day, and secondly, on average, during the case study. The results of the different signals are also compared between participants.

Chapter Six introduces the fundamental concepts of the experimental method proposed to identify the different emotional responses of the participants under different light conditions by combining the results of the two physiological signals and the behavioural responses in a three-dimensional structure for each of the four participants, without using self-report questionnaires or subjective data from the participants.

Chapter Seven presents the results obtained about emotional states from the four participants during the case study under different light conditions. The results will be obtained after analysing the data points introduced in the three-dimensional structure.

Chapter Eight discusses the results and points out the key findings.

Chapter Nine summarises the results of the research and proposes topics of further research to test the method and its dimensions and possible variations.

Glossary gathers the definitions of terms used throughout the thesis content.

CHAPTER TWO - **LITERATURE REVIEW**

2. Introduction:

The influence of the environment on the individual has been a matter of interest since the late 20th century. A variety of approaches have existed since then like Evidence-based design, environmental psychology and Neuroarchitecture, among many others. Beneficial outcomes from the features of a building have been studied since then. Researchers study the influence of the environment not only in healthcare buildings, residential homes, mental health institutions and schools - where its users are considered vulnerable people and their proper development is tightly linked to the quality of the environment but also at home and in other public buildings. This knowledge permits contemporary architects and designers to propose examples of great architecture. However, although the application on contemporary buildings is remarkable, it is not relevant for the purposes of this thesis, thus has not been reviewed.

Although every factor of the environment has an impact on the human being, the literature review of this thesis focuses only on two universal factors of the environment: the colour and the source of light. The literature review focuses on how these two factors (in isolation and combined) can impact on the behaviour and body responses of a person and how these influences can be measured objectively. Many studies focus on how these two factors impact on performance, development and reactions of normative people. However, these two factors also influence neurodiverse and vulnerable collectives such as children with autism, whose unusual condition encourages researchers to develop new ways of researching to obtain valuable data.

The impacts of the colour, and different sources of light on people with autism have been studied in the past. However, the literature review of this thesis focuses on the studies which used empathetic tools to observe or measure the influence of colour or light (or both combined) in the emotional states of people with autism. The use of empathetic tools used in neuroscience to measure these influences of the environment locates these studies on the field of Neuroarchitecture, as is the case of this thesis.

Therefore, the literature review leaves aside the influence of light and colour on the performance and learning capabilities of children with autism. It leaves aside as well as buildings which have been designed for people with autism based on findings from previous studies.

The main focus of this thesis is learning ways of measuring body responses of children with autism in the environment, and not to review how the knowledge about the influence of the colour and light has been applied.

2.1. The influence of the built environment in the user

The multifaceted Roman author, Vitruvius, stated in Book V, chapter I of De Architettura (The ten books of the architecture) that architecture is an imitation of nature to provide shelter to the human beings (Pollio, Vitruvius and H., 1960). In the book I, chapter III, Vitruvius considered that a good architect should pay attention to three meaningful concepts when designing. These three concepts are called the Vitruvian virtues and are firmitas (strength), utilitas (functionality) and venustas (beauty). Without underestimating the structure and aesthetics of a piece of architecture, this research is going to focus on the “utilitas” concept.

For many decades, the education system, thus the architects, has been drawing attention to the aesthetics and the visual language of the projects, forgetting how the user will experience the built environment, and how the environment can influence on the user’s behaviour, mood and performance (Salingaros, 2017).

The concept of functionality should not be underestimated. Functionality is the purpose of the building in all its forms. Proper design should not only provide an appropriate environment to carry out determined activities but also should satisfy the individual’s physical and psychological needs. In other words, people need to feel comfortable and safe in every space.

Frank Lloyd Wright was not the only one concerned that the design of architects might impact on our functionality, behaviour and mood (Robinson & Pallasma, 2015).

We must not forget that people perceive the environment through their senses. Sight, smell, touch and hearing become our tools to interpret the environment. Such an intuitive approach can only stimulate natural human responses. There exists a link between the brain and the experiences with the environment that turn out as body and physiological responses that modify our mood and behaviour. According to Nancy Kanwisher (Epstein, Harris, Stanley, & Kanwisher, 1999), this link takes place in the parahippocampal place area (PPA) of the brain. It is believed that the neurotransmitters react to stimuli from the environment; therefore, the brain reacts to the environment. Moreover, in the process of perceiving the environment, both psychological and biological instincts play a significant role altogether (Kuijsters, Redi, Ruyter, & Heynderickx, 2015).

Therefore, the design of architecture influences the user's mood and behaviour (Bell, Green, Fisher, & Baum, 2001).

Recently, many different design approaches have emerged to support that the built environment can improve human health and well-being. However, the approach that seems to have a more holistic and scientific-based approach regarding the influence of the environment in human's reactions and the mood is the multidisciplinary approach called Neuroarchitecture.

2.2. The new science: Neuroarchitecture, the combination of various disciplines with the same goal

As previously mentioned, the knowledge that nowadays receives the name of neuroarchitecture became a matter of interest in the late 20th century for scientists, architects and neuroscientists who saw a clear relationship between the human brain and the architecture, especially between the characteristics of the healthcare environments and the outcomes of the patients.

In 2003, a research team led by Dr Fred Gage, a senior neuroscientist at the Salk Institute, from San Diego, USA, founded the Academy of Neuroscience for Architecture to study this relationship between brain and body reactions and the environment. The Institute states that its mission is "to encourage and spread knowledge that associates neuroscience research to an understanding of the human body and physiological responses to the environment". Architects are the partner who applies this knowledge to serve society. This synergy received then the name of neuroarchitecture.

Different neuroscience studies have provided awareness about how the built environment impacts our body responses and mood (e.g. Vischer and Zeisel 2008; Papale, Rampinini, and Stewart 2016). These studies have shown how powerful can be the architecture by improving the well-being, even healing, and improving the professional outcomes of those who experience the building.

Although this relationship between brain responses and the environment was a matter of interest since the late 20th century, the innovation of Neuroarchitecture was the incorporation of “empathetic technology”, objective tools that can help in understanding the brain’s reaction to specific features of the environment and the affective state of a person (e.g. Zhang et al. 2018; Wilms and Oberfeld 2016). These tools are electrodermal activity (EDA) sensors, heart rate detector devices, respiration rates and electroencephalograms (EEG), among others. The evidence-based environmental design emerging from the use of such tools would be the critical factor that would encourage awareness of the influence that architecture has on different areas of a person, such as people’s mood, behaviour, performance and well-being.

There are many different ways to face this intriguing work. For example, Zhang *et al*. (Zhang et al. 2018) tackle this question by using electroencephalogram and functional Magnetic Resonance Imaging (fMRI) tools to assess the performance in the built environment psychologically, and, after analysing the data collected, they can propose new design guidelines.

Others used observation techniques to analyse the influence of a building in people’s well-being. Roger S. Ulrich (Ulrich, 1992) and Horsburgh (Horsburgh 1995) pointed out the importance of the ‘utilitas’ (functionality) concept of Vitruvius in healthcare environments for patients and staff. The pragmatic emphasis on the design of hospitals often produced environments that could be considered too “institutional, stressful and detrimental to care quality” (Ulrich, 1997). A healthcare environment has to be pragmatic. It not only has to help the patients to deal with their illness and stress but also needs to be a proper environment so that professionals can perform better and in better conditions (Ulrich, 1991). According to Ulrich (Ulrich 1991, Ulrich 1992), a well-designed environment can improve health by reducing anxiety, lower blood pressure and lessen pain. Meanwhile, a poorly designed hospital would provoke the situation that patients could need to remain in the hospital for longer and to rely more on antidepressants and other medication.

Many features of the environment result in having a direct relation to the outcomes of the patients. For example, it has been proven that noise elevates both sleepiness and heart rate

(Hilton, 1985) and also stresses staff, which would negatively affect the medical performance (Evans & Cohen, 1987). A lack of windows increases anxiety, depression and delirium (Keep, James, & Inman, 1980). Moreover, nature and sunny views from the room alleviates depression, and thus provokes shorter stays for people with depression (Beauchemin, 1998). Those patients who had nature views from the room had shorter stays. The patients also received far fewer negative evaluative comments, tended to have only minor complications and needed fewer doses of strong painkillers than the patients who had views to a wall (Ulrich, 1984). Having sunny rooms also resulted in more favourable outcomes for the patients. For example, coronary critical care had lower mortality in sunny rooms rather than patients in rooms north-oriented overlooking spaces in shadow (Beauchemin, 1998).

Other features of the environment are considered as well. For example, flooring material seems to be a big issue for patients. Elderly patients walk more comfortably and fall less with carpeted surfaces, and family members make longer visits in carpeted rooms than covered with vinyl (Ulrich, 1992). However, employees and staff from healthcare buildings prefer vinyl for hygienic reasons (Epstein et al., 1999; Willmott, 1986).

Features of the environment such as furniture (Merlin & Gotestam, 1981), multi-bed rooms (Shirani et al., 1986), and the art displayed in the rooms (Ulrich, 1991, 1992, 1999), also show the importance of the ambient environment, and thus architecture, in the patient and staff outcomes.

After several studies related to healthcare and human behaviour, "there is suggestive evidence that aspects of the designed environment exert significant effects on clinical outcomes for patients" and the clinicians (Rubin, Owens, & Golden, 1998).

To sum up, evidence-based supportive design in healthcare facilities seems to reduce stress and anxiety for patients and their families, reduce the pain and improve sleep quality of the patients, resulting in faster and more successful recoveries. Moreover, evidence-based supportive design also provides many benefits for employees and better performance (Ulrich, 1992).

The design of offices, public buildings like shopping malls, housing and schools would also influence user behaviour in many different ways. Standard features, such as the materials and the colours, the furniture, the organisation of the space and the light, can affect people's behaviour and mood and can be designed in architecture in order to achieve different outcomes. These examples emphasise the important role that the environment and the architecture can have on the health, development and the behaviour of a person when interacting with the environment.

Understanding how the environment impacts individuals is compulsory for improving personal well-being. Collaboration between neuroscientists and architects helps architects to understand the reactions but also to invert the process: it could be possible to design to obtain specific neurological responses. Possible outcomes could be, for example, increased concentration levels, creativity, efficiency or even mood changes, among others.

Comprehending the strong relationship between the brain and the environment, and its consequences in mood, health and behaviour, call all design solutions performed in the past into question. For example, studies about visual patterns and visual discomfort have been carried out with surprising results. Visual, geometric and repetitive patterns can be detrimental, provoking neurological and behavioural consequences such as visual stress. Repetitive geometric patterns can provoke discomfort (Wilkins D. E., 1984), headaches (Marcus & Soso, 1989) and epileptic seizures (A J Wilkins et al., 1979), can infer in reading (Arnold J Wilkins et al., 2007), and performance of tasks (Singleton & Henderson, 2007) and can even interfere with walking trajectories (Leonards, Fennell, Oliva, Drake, & Redmill, 2015). The detrimental influence of geometric patterns can be especially adverse for those who suffer from mental and neurological difficulties, such as people with Tourette Syndrome and with autism spectrum disorder (Ludlow, Wilkins, & Heaton, 2006).

Among all the possible features of the environments that could be investigated, colour and light seemed to be one of the most influencing and universal factors. There is no colour without light. They are present in hospitals, offices, schools, houses, public buildings. Light and colour are everywhere. Without it, our perception of space changes completely.

2.3. Lighting and colour and its influence in the mood and behaviour:

The influence of the colour in the mood was mentioned by Goethe (1840) in his book *Theory of Colours* in which linked warm and cool colours to emotional responses. Colour, apart from being present in the environment in many different traits and different ways, is also present in light.

Light is one of the most influencing features of the environment. It is omnipresent in the natural world, and it has to be designed in the built environment.

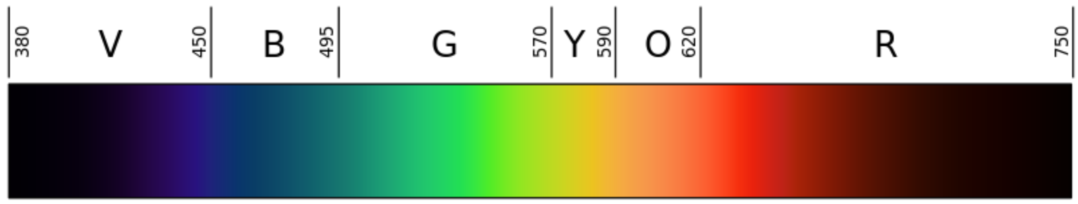

Figure 2. 1. Wavelengths (nanometers) that comprise the light spectrum visible by the human eye: from 380nm to 750nm and their respective colours.

The first study on the matter was carried out by Pressey (1920). Pressey found that the autonomic nervous system (through pulse and respiration rate) reacted the same way to warm colours and cool colours and there was no difference in performance; however, the brightness did boost the rate of performance. Later studies contradicted these results showing a significant influence of the colour and the light in people's mood and behaviour as will be shown in these lines.

According to Kaiser (Kaiser, 1984), the colour can influence an individual directly or indirectly. By directly, Kaiser understands that the colour influences the body responses without cognitive intermediary response. For example, the wavelength of the colour is observed by the body through the skin or the eyes, producing an effect on the physiological responses. However, if any cognitive association is done when perceiving the colour, the influence of the colour on physiological processes will be indirect. In other words, the colour and the light might influence biologically (directly) and psychologically (indirectly).

Both the colour of light, and the source of light influence brain activity, mood and performance without our realisation. The colour wave can be sensed through the retina (Zaidi et al., 2007) and even sensed through the skin or with the eyes closed (Hoang et al., 2008), suggesting that visually impaired people are also influenced by the colour and the light. From a biological point of view, the influence of the wavelength colours in our body can be explained by explaining the impact and properties of the natural light, as our body is regulated by natural light.

Daylight regulates our body clock and intensifies the level of activity and, for instance, influences a person's circadian rhythms, triggered by photoreceptors (rods and cones) of the retina which send the information to the suprachiasmatic nucleus in the brain, and mood. Depending on the wavelength of the light, the level of activity and the wakeful state is higher or lower. When the retina is exposed to shorter wavelength natural light (daylight from the early morning which is cool and blue) the pineal gland stops secreting melatonin giving us more energy to wake up. When the retina is exposed to longer wavelength natural light (daylight from the afternoon, which is warm and red), more melatonin is secreted and this secretion of melatonin aids to sleep. This process receives the name of the circadian rhythm.

Therefore, the human circadian rhythm causes higher secretion of melatonin at night, thus aiding sleep. For this reason, when the eyes are exposed to artificial short-wavelength light (such as blue light), the pineal gland misreads the signal, thinking that the artificial light is actually natural light from the early morning, and disrupts the circadian rhythms: melatonin is suppressed and the level of activity increases (Thapan, Arendt, & Skene, 2001; Warman, Dijk, Warman, Arendt, & Skene, 2003). These influences on the circadian rhythm can cause sleep and mood disorders such as sleeping disorders and seasonal affective disorders.

Consequently, blue light (420-440nm) suppresses more melatonin than green light (534-545nm); and red light (564-580nm) has almost no effect on melatonin suppression at all (Thapan et al., 2001) and the secretion of melatonin, which aids to sleep, is encouraged under red light or long-wavelength conditions (daylight from the afternoon which is warm and red). This fact means that blue light is more arousing than red, in other words, shorter wavelength colours are more arousing than longer-wavelength colours (Kaiser, 1984; Wright, 1998). These findings also suggest that shorter wavelength light increases alertness (Cajochen, 2007). In addition to that, blue light, compared to yellow light, is expected to improve performance in tasks which require high levels of concentration (Cajochen, Frey, Anders, Späti, & Bues, 2011; Lehrl et al., 2007; Viola, James, Schlangen, & Dijk, 2007).

Certain characteristics of light, such as the colour temperature (CT) and the illuminance can influence the Circadian rhythms and behaviour directly. The colour temperature refers to the sensation of warmth (yellow, orange and red tones) and coolness (green and blue tones) of the light. It is measured in Kelvins; the more CT the light has, the cooler it is, and vice versa. The illuminance, on the other hand, is the luminous flux (lux) incident on a surface. Lewy (1980) found that at least 1000lux of white light was necessary to suppress melatonin in healthy humans. In comparison with animals, humans require much higher light illuminance to suppress melatonin.

In terms of CT, a sunny day is around 6000-7000K. For office spaces, it is believed that cool light which would simulate daylight (6000-6500K) to help concentration (Weitbrecht, Bärwolff, Lischke, & Jünger, 2015). For domestic settings, a warmer light is commonly used (2000-3000K) to enhance relaxation. For non-specific places, neutral cool light is often used (3800K-4500K).

Regarding behaviour, warmer light (3000K), compared to cooler white light (4200K) seemed to boost the willingness to help and solve conflicts (Baron & Rea, 1992). As the population is very diverse, and architecture is not perceived in the same way by everybody, generalisations can be misleading. Gender might play an important role on the results according to the results of the study carried out by Knez et al. (1995) where female participants had a more positive mood under warmer light conditions than cooler light conditions. Just the opposite was found for men.

Knez et al. (2001) also observed that older people (c. 65 years old) perceived an illuminated room as less bright and warmer than younger people (c. 25 years old). The older people from the experiment also seemed to preserve a negative mood under cool white light (4000K), whereas the younger people were the opposite.

Kuijsters et al. (2015), also suggested that the perception of the atmosphere, as well as the colour perception, may differ with age. The visual system changes over time by reducing the pupil size, resulting in a reduction in sensitivity to light. The researchers induced sadness and anxiety to older adults and focused on improving the mood of the participants with affective ambiences obtained with different light conditions. The researchers induced sadness by showing the participants a sad film segment from 'The Champ' (2'51''), and induced anxiety by showing the participants an anxious film segment from 'The silence of the lambs' (3'29'')). Both short movie excerpts were selected from the database of Gross and Levenson (1995). The 'sad' elderly people were physiologically more aroused thanks to an activating ambience (illuminance 150lux and CT 3400K) more than in a neutral atmosphere (higher illuminance 325lux and higher CT 4000K). The 'anxious' elderly could also be affectively calmed with cosy ambiences (lower illuminance 120lux and lower CT 2700K) being less aroused and showing higher pleasure scores than in the neutral state. These findings emphasise the idea that the environment can have an important role in the quality of life of the vulnerable people and that architects and designers are responsible for the improvement of the comfort of these people.

Apart from changing the mood, lighting can also boost cognitive skills and performance in specific work environments. Peter R Mills et al. (2007), found that a high colour temperature (17000K) appeared to have contributed to improvements in well-being, functioning, productivity and work performance amongst the participants of a study.

Examples like the ones mentioned shed light on many different questions about light and its influence on vulnerable individuals who are not entirely developed. That is, how light can affect children in their academic results and behaviour in the school.

According to Sleegers et al. (2012), it was observed that high spectral blue light (for example, 9.000K) activates and increases the concentration and capability of performance because the light simulates the midday sun. However, if the light levels are reduced, and the colour temperatures are warmer (for example 2700K), the body interprets the light as an evening atmosphere and relaxes and calms.

Sleegers et al. (2012) developed an experiment where children were exposed to four different types of light in the school, depending on the activity they were doing. These various settings were: energy setting used to activate the pupils at the start of the day and after lunch (illuminance 650lux and Colour Temperature (CT) 12000K – cold blue light). Focus setting used to boost concentration during challenging tasks such as exams (1000lux and CT 6500K – bright white light). The calm setting, relaxing ambience used for collaborative learning (300lux and CT 2900K – white light with warm red colour tone), and finally, Standard setting, used for regular activities (300lux and CT 3000/4000K – standards white light). These parameters showed impressive results: the reading speed increased by almost 35%, the frequency of errors reduced by nearly 45% and the hyperactive behaviour also dropped by 76%. Even though these findings suggest that the lighting proposal is very effective, showing outstanding results, it would be worth studying the effects of this lighting in the circadian rhythms and the sleep quality of the students.

Although the influence of the colour and light in our body responses cannot be denied based on the literature just mentioned, the results found regarding the influence of light on people's behaviour and mood are not always consistent.

Despite the evidence, many intrapersonal, situational and cultural factors can influence the colour perception. Therefore, from a <u>psychological point of view</u>, the body has different physiological reactions to colour as they are related to the psychological experiences, context and functioning (Goldstein, 1942). In terms of the biological influence of the light, according to Goldstein's opinion, warm colours such as red and, to a lesser degree, also yellow, seem to be qualified as stimulating and unpleasant on the built-environment, while green and, to a lesser degree blue, seems to be qualified as calming and pleasant, as well as considered to enhance concentration. These results may contradict those which were found in the physiological research. Therefore, from a psychological point of view, red (and yellow) compared to green (and blue) is more arousing and undermines performance when concentration and precision are required. However, it is important to bear in mind that Goldstein's work is not based on scientific evidence.

Colour associations play an important role in explaining the contradictory results found in the literature. For example, while blue and green, colours observed in the sky and nature, are associated to nature and relaxation, the colour red, observed in warning signs, is commonly associated with negative feelings such as “danger”. Colour red is also observed in the teachers' corrections and can also be associated with failure in the academic environment. These social and contextual associations can also influence the mood and body responses of the individuals. Findings showed that the perception of red before doing a task impairs performance compared to the perception of green or an achromatic (e.g. grey) colour. The exposure to red evokes avoidance motivation, as indicated by participants’ choice of easy relative to challenging tasks. Red light also impairs performance on IQ tests (Elliot, Maier, Moller, & Friedman, 2007).

Most of the studies have compared the difference in mood and performance comparing long-wavelength colours such as red to short-wavelength colours such as blue; more than any other colour. Wavelength has been the significant property of the light studied. Literature suggests that long-wavelength light, like red, lead to higher arousal than medium and short wavelength lights such as green and blue (for example, Jacobs 1972; Kwallek et al. 1996; Yoto et al. 2007). That is colours like red seem to be more activating than blue or green, contradicting findings on the study of the biological influence of light.

These results can result from the associations a person has already made based on past experiences, or the cultural context, as few studies associated similar results to other associations of the colours. According to Soldat et al. (1997), colour red undermines cognitive performance compared to blue because the colour red is associated with happiness and could evoke heuristic processing and blue is associated with sadness and could evoke systematic processing. Nevertheless, there is no scientific evidence that red does evoke heuristic processing and blue evokes systematic processing.

Even though these studies have linked the increase in arousal under red light conditions to poor performance, recent studies indicated that an increase in arousal could indicate mental workload (Novak, Mihelj, & Munih, 2010). For this reason, it would make more sense that the poor performance under red light was because the social and experience associations that have been linked to the colour itself than correlated with the levels of arousal.

Some researchers suspect that the colour associations occur due to evolutionary tendencies to colour stimuli (Jacobs, G. H. 1981; Mollon, 1989), based on adaptation and survival (Byrne & Hilbert, 2003; Hutchings, 1997). If that were true, many human beings would respond to the colour similarly, and the colour associations would provoke specific and similar cognitive responses. These results may suggest that these psychological associations are as innate as if these associations were already in our genes, suggesting a response similar to the obtained due to the biological influence. However, there is no consistency in scientific publications about these evolutionary colour associations, and its influence in the human responses. Thus, type of colour, cultural factors, age and gender, among others, play an essential role in the association of colours.

For this reason, it is crucial to bear in mind the context because any colour can have a different meaning in different contexts, that is, different implications for feelings and behaviours. For example, while colour red might be associated in many western cultures with failure and danger in the academic environment (Elliot et al., 2007), in other contexts, the same colour is often associated with passion and love, and in eastern cultures like the Chinese, the colour red is associated with luck, joy and happiness. In other words, in terms of the psychological influence of the colour and the light, every colour would evoke different emotions depending on the context and the characteristics of the person.

2.3.1. Properties of the light:

Different findings also show that the properties of the light play an essential role in the influence of the light in the mood of the people.

Light has more characteristics than just the wavelength. Any of these differences found in different publications might be provoked by the difference in hue, saturation, and/or intensity of the light. The hue of the light is the colour itself. The saturation is the purity of the hue. If the colour is 100% pure, 100% saturated, it means that the colour does not have any addition of grey. Some investigations considered that the saturation has a stronger effect on mood that the hue (Suk & Irtel, 2010a; Valdez & Mehrabian, 1994). The intensity also referred to as brightness, refers to the mix of white and black in the colour. The more white has been added, the more intense and brighter it is; the more black has been added to the colour, the darker. The intensity is then defined relative to a reference white and ranges from 0 to 100, measured in %, where 100% represents the amount of white compared to the 0% of black. Another concept already mentioned during this chapter is illuminance. Although brightness and illuminance can be confused, while illuminance refers to the luminous flux which falls on a particular surface (affected by all the elements which surround the specific surface), brightness refers to the sensation of luminosity or darkness in the room. Brightness is the term used for the subjective impression of the luminance and luminance is the luminous flux emitted from a source or surface, in a certain angle, detected by the human eye.

Variations in any of the properties of the colour and light can impact affect, cognition, behaviour and the psychological functioning (Elliot, 2015).

Despite that, most of the previous work on performance or emotional effect of colour (e.g. Elliot 2015; Kaiser 1984) did not monitor the properties of the light mentioned, generalising the results with no consideration that there can be many types of the same colour, and that these types can have different impact on the mood and body responses of a person. For example, when researchers discussed the influence in productivity or mood of the colour red, it is not possible to know which kind of red was, and this is an important part of the information missing. For this reason, controlling the properties of the colour when doing tests is essential, so the impact the colour had in mood or behaviour can be related to the properties of the colour later.

Kwallek et al. (1996) examined the effect of different wall coloured offices. The offices examined had walls coloured red, blue-green and white. The study focused on 90 workers' mood and productivity and observed that workers on the red offices reported more unpleasantness and distractions ratings than those in the blue-green office, however, they were more productive and made fewer errors than those in the blue-green or white office. These results are in line with Knez (2001), who suggested that blue diminishes attention and concentration. However, these results contradicted results from Elliot et al. (2007), who defended that red light impairs performance on IQ tests compared to the perception of green.

However, Kwallek et al. (1996) stated that, while the colour scheme of an office might not be sufficient to determine productivity because the impact of the interior design might be different from person to person, depending on the intrinsic and idiosyncratic characteristics of every person, the mood can be influenced by the colour. These findings show that productivity and mood have no relationship.

These differences in results might respond to the fact that the properties of the colour might be different, but these properties were not considered when experimenting. Thus, the results cannot be compared because of doubts about the methodology.

2.3.2. The psychological and emotional influence of the colour on light and other features of the environment:

There is no real placebo to light to evaluate and compare the influence of the light in the body responses and emotional state of a person, and subjective ratings can be, most of the times, insufficient to interpret the impact of the light. For this reason, many physiological measures have been used to study mood and emotional processes combined with the self-report questionnaires. Electrodermal activity (skin conductance) and cardiovascular activity (heart rate), among others, correlate of arousal, providing objective measures instead of subjective interpretations of the arousal. Other body responses and objective measures observed in the literature include electroencephalograms (EEG), respiration rate, eye blink frequency, and blood pressure.

Electrodermal activity (EDA), as it will be explained in-depth in Chapter Five, defines autonomic changes in the electrical properties of the skin getting the information from the variations of the sweat glands in the skin. The sympathetic nervous system controls sweating, so EDA is linked to emotional and cognitive processing and is an essential and objective variable in psychological science. EDA measures changes in arousal and can inform cognitive states and emotions such as stress, excitement and fear, among others.

Some studies reported that EDA, therefore the level of arousal, is higher when observing the colour red or long-wavelength colours. For example, Nourse and Welch (1971) observed stronger EDA response when observers looked at violet colour than when they looked at green colour. However, this significant difference was only observed during the first 60 seconds that the colour was experienced. Results during the rest of the period were similar. These findings indicate that the difference in EDA might be provoked for the change of stimuli and not necessary by the colour itself.

Gerard (1958) also reported that EDA was higher during red or white light than under blue light. Similarly, Wilson (1966) found that EDA was higher in red light exposures than under green and blue light exposures. Wilson also suggested that the order in which the stimuli are presented might be important as EDA responses were different when green was presented before red or when red was presented before green. However, the brightness of the colours of Wilson’s experiments was not the same, and this fact can influence the results.

Jacobs and Hustmeyer (1974) observed a difference in EDA measures under yellow, green, red and blue (with same brightness), but did not observe differences in heart rate and respiration ratings. The more arousing colour was red, then followed closely by green, yellow and blue.

Thus, red and green were more arousing than blue and yellow, but the red and green were pretty similar in terms of EDA. While this work agrees with Gerard (1958) in the comparison between red and blue, it disagrees with Wilson's (1966) in the difference of arousal between red and green, who found that red was significantly more arousing than green.

The preference for colour is a matter that has been debated in terms of electrodermal activity, as well. While Day and Sobol (1967) defended that the colour preference is correlated with the EDA measures; Gerard (1958) and Wilms (2016) suggested that there is no relationship between colour preference and electrodermal activity. It is not a matter of somebody liking a colour, whether the colour has a good impact on the person or not.

Caldwell and Jones (1984) collected measures of EDA, eye blinks, heart rate, finger pulse volume and EEG activity, and found no differences under red, white and blue light. One of the reasons behind these results might be that the exposures were less than a minute, and the time might be too short to see any changes in body responses. However, as seen in Nourse and Welch (1971) work, they only found a significant difference between violet and green during the first 60 seconds that the colour was experienced.

As aforementioned, other tools can also be used to interpret the influence of colour. For example, Ali et al. (1972) found that the red light was more arousing than blue light because red light suppressed more EEG alpha activity.

Frequently, psychologists use physiological measures with emotional ratings, when discussing emotions, using the term valence to categorise the emotions subjectively. "Positive valence" is used to refer to positive feelings such as joy and attractiveness. "Negative valence" is used to refer to negative feelings such as fear and avoidance. Researchers, who studied the emotional valence concerning different colours of light, reported contradictory findings. Some research suggests that short-wavelength colours inspire more satisfying feelings than long-wavelength colours (Valdez & Mehrabian, 1994). However, Kuller et al. (2009) participants' found more satisfying the red room instead of the blue one.

Both the arousal and the valence ratings (the positive or negative tendency of the feeling) seem to increase if the colours are brighter (Cajochen, 2007). The valence ratings also increase if the saturation of the colour is high. However, if it is too saturated, the outcome is the opposite, and the valence rating starts to decrease. If the colours are too saturated in an office environment, the male workers are more keen to feel depression, confusion and anger (Kwallek et al., 1996).

Wilms et al. (2016) carried out a study considering three different hues, three different levels of saturation and three different levels of brightness and studied the influence that these thirty combinations could have in the emotional valence, skin conductance and heart rate. Researchers showed that the three colour dimensions had a significant influence on the emotion ratings and that the higher saturation corresponded with higher arousal ratings. The hue influenced arousal and increased from blue to green and from green to red. When controlling saturation and brightness, the arousal was affected only for highly saturated colours. Overall, red was the most arousing colour, followed by green and blue. These results coincide with previous work on the matter (Suk and Irtel 2010; Oberfeld et al. 2009; Yildirim, Hidayetoglu, and Capanoglu 2011; Zieliński 2016), and also with previous work that did not consider the different properties of the light (Gerard, 1958; Wilson, 1966).

Even though many researchers have combined both physiological measures and self-report questionnaires to evaluate the influence of the colour on mood, Ziems et al. (1998) defended that the arousal was a more determinant indicator of sensory processing than emotional valence.

It should not be forgotten that self-report questionnaires are, as the name already indicates, questionnaires composed by subjective answers. These answers can be ambiguous sometimes because of the inability to evaluate our emotional levels, and incomparable, as every participant can evaluate their affective levels differently.

To reduce the use of subjective ratings, the use of empathic tools has been of increasing importance in the field. While many methods have been already used and proved their efficiency, other tools are still to discover its effectiveness when evaluating the influence of the colour and light in mood, performance and behaviour.

For example, thermal imaging appears to be a promising tool for the study of spontaneous responses to emotions (Merla, Garbey, Sun, & Pavlidis, 2007). Thermography is a non-invasive technique employed in psychology to study autonomic physiological responses to emotions. The temperature of the body brings essential information about nonverbal behaviour, which is not subject to subjective interpretations as are some other measures, such as emotional valence. It could be a solution to measure physiological signals without attaching devices to the skin or interrupting experimental procedures to ask the participants how they feel. To the best of our knowledge, thermography has not been used before to study the influence of the colour in the parasympathetic system or mood. However, it seems a promising tool that can be combined with others aforementioned.

2.3.3. Colours studied:

According to Nurlelawati et al. (Nurlelawati, Mohd, & Said, 2011), the influence of red colour has been the most studied, then blue, white and green. Yellow suffers from a lack of investigation, although many researchers also find that the research on white colour might be weak. When Gerard (1958) studied the impact of the colours white, blue and red, the results of white showed that the responses varied noticeably, and there was no consistency. It was only mentioned that sometimes body response and subjective mood ratings could be similar to the ones collected in red conditions.

As we can see, findings on the influence of the colour and the light considered from a biological point of view conflict with the findings observed from a psychological point of view. There are many contradictive findings regarding the influence of the colour of the light in people's mood, performance and behaviour. These incongruences reveal that either the biological or psychological perspective can have a predominant influence and that these can produce many different results. Although the biological approach might seem, *a priori*, generalisable among most of the individuals, from a psychological point of view, the colour of the light is a dependent variable, as the cultural context and the intrapersonal factors impact on the perception of the colour (Fetterman, Liu, & Robinson, 2015). Taking context – culture, gender, age, a variant which depends on the colour – is vital for understanding the responses to the light.

However, many questions arise from these studies: which influence of the light is stronger and would prevail, the biological or the psychological?

If the colour of the light affects a person differently over the years, as Knez *et al*. (2001) and Kuijsters *et al*. (2015) suggested, how can architects apply these findings without knowing the final results they might be obtained from the users in their buildings?

Can the results be generalisable to all the population? Do all the brains of all the individuals perceive the stimuli the same way?

2.4. A diverse neurological population:

To be able to generalise and hypothesise about how the brain reacts to specific features of the environment, it has been inferred from previous approaches studying light effects on neurotypicals that scientists have presumed that most brains would react similarly. Nevertheless, the population is highly diverse neurologically speaking.

What happens when we speak about a population with intellectual disabilities or any other mental or neurological illness or disorder such as epilepsy, dementia or autism? Would these brains react to the environment the same way?

This matter would directly affect individuals with neurological disorders such as dementia, Alzheimer's Disease or Autistic Spectrum Disorder (ASD). For example, Goldstein (1942) declared that some of Parkinson's disease symptoms could be minimised in severity if the individuals are not exposed to red or yellow colours. Studies also showed that the use of vivid colours could improve the short-term memory performance of patients who have Alzheimer's Disease compared to the use of identifiable forms (Cernin et al., 2003).

It is already known that these disorders present neurological differences from the rest of the population. Light and colour can influence the release of dopamine greatly, thus influencing the emotions.

However, people who suffer from these types of disorders have limitations on their communication skills that do not allow them to explain how they feel and how the environment affects them.

As aforementioned, analysing the emotional valence of the participants is a broadly used option to understand the influence of the light in people's mood. However, emotional valence cannot be measured in people with cognitive difficulties who cannot understand and express how they feel and why. For this reason, it is necessary to recognise, analyse and understand their reactions in some other ways. Therefore, using empathetic tools that provide physiological information such as EDA, heart rate, EEG, can be, in these cases especially, more convenient, informative, accurate and objective.

2.4.1. A case study: Autism

According to the National Autistic Society, Autistic Spectrum Disorder (ASD), commonly known as 'Autism', but including other conditions, such as Asperger Syndrome, is a lifelong, developmental disorder that influences how a person communicates with and relates to other individuals, the social imagination, and how they experience the world around them. 1 in 100 children in the United Kingdom is affected by ASD. This figure is slightly lower than the USA in which 1-in-68 children have ASD. People diagnosed with autism would refer to those who are not in the spectrum as "neurotypical people".

A predominant characteristic of autism that can be detrimental is the presence of repetitive behaviour. Repetitive behaviours are rigid, repetitive, stereotyped and inappropriate movements, repetitive use of language, repetitive manipulation of objects, specific attachment to objects and repetitive self-injurious behaviours, among others (Kanner, 1943). These repetitive behaviours are often called tics. Their characteristics and mechanisms behind them are deeply explained in Chapter Five, Section 3. Children with autism engage more with repetitive behaviours in stressing situations. These behaviours are aggravated by anxiety, stress, anger, fatigue or excitement; and reduced during sleep, doing high concentration tasks, being distracted and in emotionally pleased situations (Harris & Singer, 2006). Depending on the type and severity of the tics, they can make “normal” life difficult.

Among all the possible reasons that can provoke anxiety in an individual with autism, the environment might be one of the most influential ones.

2.4.2. Sensory processing disorders and autism:

According to Ben-Sasson et al. (2009), in a study of children (without any specific diagnosis) born between July 1995 and September 1997 and aged between 7 and 11 years, 1 in 6 children had symptoms of Sensory Processing Disorder (SPD). Ahn et al. (2004), performed another study with younger children and found that 1-20 children are affected by SPD.

Sensory processing refers to the way that the nervous system receives information from the senses and turns it into appropriate motor and behavioural responses. A person with SPD finds it difficult to interpret and organise the stimuli from the environment because these stimuli are not (well) detected and translated differently by the nervous system. Differences in the structures of the nervous system might influence this inability to process the stimuli correctly.

There is neurophysiological evidence that many parts of the brain of a person with autism are different when compared with typically developing individuals’ brains. For example, one of the parts of the different brain, when compared to neurotypical individuals, is the amygdala, a part of the brain involved in the regulation of emotions (Baron-Cohen, 2000). Some areas of the autistic cortex implicated in colour vision are also different (Robertson & Baron-cohen, 2017). The cerebellum, the limbic system, and the corpus callosum, among others, also appear to show some differences (Volkmar, Klin, Jones, & Schultz, 2003). These findings suggest that, if the brain is different, the neuronal processes when perceiving an environment and when interacting with it will also be different, or at least, the brain plasticity might be different. In other words, the influence of the features of the environment might impact differently on people with autism and neurotypical individuals.

60% to 90% of people with autism suffer from SPD (Baranek G. T., David, Poe, Stone, & Watson, 2006; Dunn, 1999). That is, most of the people who are on the autistic spectrum might not perceive the environment in the same way as a neuro-typical person. According to Dunn (1999), people with low functioning autism (LFA), who usually “have impairments in the three areas of psychopathology: reciprocal social interaction, communication, and restricted, stereotyped, repetitive behaviour”, are more sensitive to sensation and will either have an excessive behavioural response or will tend to avoid overwhelming sensations or environments. Physical and mental health can breakdown when somebody is not able to adapt to environment, situations and experiences (Antonovsky, 1972).

Autistic children with SPD can be hypersensitive to specific features of the environment and hyposensitive to others. Hypersensitive children would feel the stimuli more intensely and with more detail, avoiding dark and bright lights, among other consequences. Hyposensitive children would not receive so much information from the stimuli (Baranek B. G. T., Boyd, Poe, David, & Watson, 2007) and might seek higher stimulation, like light, to maintain optimal arousal levels (Reynolds, Bendixen, Lawrence, & Lane, 2011).

Sensory processing disorder impedes a healthy life. Overstimulation provokes stress and sleeping disorders on people with SPD. Poor sleeping children showed more fundamental mechanisms of high arousal designed to protect and defend that are less conducive to rest and restoration (Reynolds et al., 2011). Sleep disorders are estimated to occur at 40% to 80% of people with ASD. Poor sleep quality can impact behaviours such as attention, motor coordination and cognitive performance negatively (Marlow, Naaman, Davis, & Hall, 2006; Paavonen, Räikkönen, & Lahti, 2009), but in people with autism, it also provokes affective problems and reciprocal social interaction (Marlow et al., 2006).

The fact that many groups of vulnerable individuals, like people with ASD and SPD, face health issues, stress, and sense of discomfort and unsafety due to the built environment, indicates that the architecture does not fulfil some of its primary duties. Therefore, everything in terms of design and architecture can be subject to reconsideration.

Instead of forcing people with SPD to adapt to the already established and standardised environment, annulling cognitive capabilities and influencing their health, mood and well-being negatively, new design solutions can be proposed so these individuals can explore all its capabilities without an oppressor environment.

For this purpose, it is fundamental to understand how people with autism perceive the environment and how this environment can affect their performance and mood.

2.4.3. Visual detection, “seeing the trees but not the forest.”

According to Temple Grandin (Thinking in Pictures (Grandin, 1996)), people with autism are overwhelmed by the overload of stimuli. There is much information in the environment, and individuals with ASD cannot process all the information correctly. They cannot decide which information is relevant and which is not. They receive much more information than they can process and interpret. For this reason, the first time an autistic child enters a ‘new’ environment, such as a room or a building, is very challenging.

When a neuro-typical person enters a room, they perceive in a matter of seconds the concept of the place, the proportions and the atmosphere. It is not until the individual chooses to pay attention to the objects and textures that they would start perceiving that more specific information. However, people with autism, on entering a room, are more aware of the small details, the patterns and, only little by little, might they start to interpret the whole environment. Individuals with autism are frequently faster at detecting single details embedded in visually cluttered environments. Within complex scenes, there are more predominant regions which are salient in terms of colour and contrast compared to the size and the complexity of the objects (Robertson & Baron-cohen, 2017). It is a slow process to understand all of them because it can take minutes, and as a result, this is a stressful way for a person with autism to perceive the world because they cannot anticipate situations. The overload of stimulation of the environment is overwhelming and unpleasant, provoking stress and hyperactivity to the people with autism.

According to Dunn (1999), low neuronal threshold individuals are more sensitive to sensation and their behavioural responses when experiencing unpleasant situations, and reactions are more extreme. The stress from facing unpleasant situations may cause increases in blood pressure, heart rate, ocular pressure, epilepsy tantrums, migraines, pain or, in the worst-case scenario, cot death. The environment hurts them so they might isolate themselves and avoid sensory inputs to feel better.

As the relationship with the environment is so aggressive, the person with autism might react with tantrums, tics and aggressive behaviour against others, themselves or the environment.

According to Rossana Viapino Dilascio (Autismo y Espejismo, (Dilascio, 2014)), children with autism live in a constant alert state, so their main feeling is fear. They are afraid of non-predictable situations. These fear and constant alert states directly affect the sleeping process as well (Alfano, Zakem, Costa, Taylor, & Weems, 2009).

For them to experience a non-threatening environment, they have to create routines so that all experiences are known and expected. They base their comfort-zone on a routine applied to all aspects of life.

2.4.4. The importance of the environment in individuals with autism:

The environment is omnipresent, so it plays a significant role in the life of people with autism and thus drives their behaviour. For this reason, nowadays, it is a rising research topic, and the responsibility to create a healthy and friendly environment that makes them feel safe and comfortable relies on architects and designers. It is expected that, as a designed environment that has not been designed for people with autism can trigger many detrimental symptoms, a thoughtfully designed environment could minimise the symptoms, improving learning capabilities and integration into society.

In order to do so, understanding how neuronal differences affect how people with autism perceive the world is vital. In recent years, it has been broadly accepted that the different features of the environmental impact on people’s mood, behaviour, performance and productivity. However, there is little information about how these environmental factors affect the population with autism. As seen in section 2.4.2., most of the people with ASD suffer from SPD, but every affection is different. In other words, every person might have a different way of perceiving the environment; therefore, the different features of the environment might have a different influence on every person with ASD.

Many design solutions approved in the past, with no awareness of neurological diversity, were based on the social and cultural context that influences human behaviour daily. According to Mitchell et al. (2004), when perceiving a space, people with autism do not use prior knowledge as much as neurotypical people. In other words, although people with ASD are not entirely immune to the prior knowledge, it has less influence on the visual-space perception of people with autism, so their perception might be more objective and less influenced by prior experiences than neurotypical people. Therefore, previous design solutions might not succeed in satisfying individuals with autism needs.

Considering the literature regarding differences in processing the external stimuli provoked by the different structures of the brain, among the different associations that can be linked to the environment interpretation, it would seem that the design of the environment needs to be reconsidered and designed from scratch to fulfil people with ASD and SPD expectations and needs.

There exist some broadly known recommendations suggested by authors like Humphreys (2005), Mostafa (2007) and associations like The Kingwood trust (Brand, 2010). Neutral rooms with no distractions are better for concentration and sleep. Acoustic isolation is always recommendable to avoid noises from adjacent rooms and outside. Pale colours are suitable for the walls and plain materials with no patterns and severe textures. Storage is needed to 'hide' objects so that they are not on display. Nevertheless, a scientific approach and evidence-based design are necessary to address this challenge which is likely to be idiosyncratic.

The concern of improving performance and behaviour in school has meant that academic environments have received more attention than other types of environments, so far. It has been considered that previous design solutions have distanced children with autism from learning, thus preventing them from integrating into society (Mcallister & Maguire, 2012). Mostafa (Mostafa, 2007, 2014), worked on determining autistic-specific design guidelines that architects should consider to create an ideal academic environment. These design guidelines focused on acoustics, spatial sequencing, escape spaces, compartmentalisation, transition spaces, safety and sensory zoning. The researcher studied these features of the environment by analysing the attention span of the students, the response time and behavioural temperament. Mostafa suggests that the longer the attention span, the better; the shorter the response time, the better; the less repetitive behaviour, the better. Acoustics can influence the capability of children with autism in speech and language acquisition. Soundproofed classrooms proved to increase the attention span more than three times, the responses were quicker, and the behavioural temperament also improved. Spatial sequencing of functions or compartmentalisation (from the most important to the least) intervention also improved the three studied aspects. Research on escape spaces, which are neutral sensory spaces with minimal stimuli, showed that they could have positive outcomes when the child is feeling overwhelmed by over-stimulation. Compartmentalisation is essential to control the over-stimulation. Transition spaces should be designed to avoid drastic changes so the children can cope better with the changes of rooms and activities. Safety is a vital point. Many children with autism, who suffer from SPD have problems identifying hot surfaces, among other hazardous situations. Paying particular attention to all the possible risk factors to act accordingly is crucial. Mostafa realised, as previously did Delacato (1974) and later Coulter et al. (2009), that the perception of each individual with autism is different and cannot be generalised, and that these recommendations might be reconsidered with every user.

For this reason, Mostafa proposed the “Sensory zoning” concept, sensitive segregation of autistic children based on their sensory needs instead of their cognitive performance, age or the function of the room. Khare et al. (2009) also added that designers, when working in academic infrastructures for children with autism, should consider values such as durability and maintenance when choosing materials. Outbursts from children with autism can result in damaging the close environment severely.

Kinnaer (2015) reviewed six autobiographies of people with high function autism who explained their relationship with the environment and extracted a few pieces of advice for architects and designers. First of all, addressing the hypersensitivity or hyposensitivity by adding or reducing, respectively, the stimuli of space is essential. Every situation is highly idiosyncratic, and the challenge is to find an environment that could suit every person with autism. For this reason, the most broadly extended suggestion, as previously seen, is creating neutral spaces with sufficient storage to reduce over-stimulation and irrelevant stimuli (Brand, 2010). In the case that more stimuli are needed, they can be added to the mentioned neutral room. Another recommendation was to link every space to a specific activity to give people with autism a sense of control of the situation and predict what will happen in every space. It also came to light that orientation and navigation might be problematic for people with autism, so signage and carefully indicated directions could help to make people with ASD feel more independent and less stressed (Gerland, 1996; Landschip & Modderman, 2004).

The review of the six biographies suggested, again, and emphasised, that even though a few similarities can be found on how people with autism perceive the environment, the interpretations of the space and the different factors of the space can differ depending on the context and the person. For this reason, testimonies from people who suffer from high function autism cannot be considered as generalisable or as a scientific phenomenon, or enough to create a holistic design approach. Although these are all true statements from people who are in the spectrum, people who are located on another side of the spectrum could feel profoundly different to the same stimuli. In other words, these guidelines can be considered as a trustworthy starting point for some people, but more scientific research about both the perception of the environment of people with autism and research about the specific individual who will use the facilities, is needed before the advice can be applied.

The individual and natural way of processing of people with autism can be influenced by their neurological system, character, experiences, and knowledge, and every child might have their combination of factors. The individual-differences concept could explain why visual symptoms differ incredibly between children in the autism spectrum, and why some children can present hypersensitivity and others can present hyposensitivity. For this reason, even a carefully designed space might not be satisfying for everybody because not every child perceives the environment in the same way, and unique space for everybody might not satisfy the needs of many of them. How can we know how a child with autism processes the environment and other visual factors?

How can architects design for people with autism if the perception varies as much? How can architects and scientists evaluate how any kind of environment is beneficial or not for people with autism without resorting to the evaluation of performance, as seen in the evaluation of the academic environment? Should architects focus on the idiosyncrasy of the individuals instead of trying to design for masses?

Psychologists frequently use subjective ratings to evaluate arousal and valence, in order to understand the positive or negative influence the built environment (or certain features of the environment) have in the people. Lately, these questionnaires have been combined with physiological measures, as well.

Unfortunately, some children with severe autism, might not be able to perform self-report questionnaires and other approaches need to be used to understand how they feel, such as physiological approaches.

To measure the levels of arousal of children with ASD, Schoen et al. (2009) used electrodermal activity to see the difference in arousal between children with autism, children with SPD and neurotypical children. Results from the study showed that children with sensory processing disorders had higher levels of arousal and higher physiological stress reactivity to sensory stimuli. Neuro-typical children had a similar response to sensory stimuli as children with SPD, indicating that children with ASD without sensory processing disorders might be more hyposensitive to the environment.

Although some factors have been studied in recent years regarding the academic environment for children with autism, there are two features of the environment which have been hardly studied and, as previously seen, might have a strong influence not only in the academic environment but everywhere. These factors are the colour and the source of the light.

2.4.5. Lighting and colour perception in people with autism:

Colour is considered to be the essential visual experience to human beings (Adams & Osgood, 1973), to help to enhance memory performance (Wichmann, Sharpe, & Gegenfurtner, 2002), and can attract attention more than other features of the environment, especially for individuals with ASD. Colour, in any possible way, can boost the attention level and increase arousal. Colour, therefore coloured light, can also act as a mood changer. Yet there is not much information about how colour and lighting might affect people with ASD's mood and performance.

In terms of colour perception, as expected, the literature shows that colour perception is different in children with autism compared to typically developing children matched on age and non-verbal cognitive ability. Differences not only in the anatomy and functional organisation of the brain of those who have ASD but also differences in the rods and cones component of the eye, suggested that the perception of colour is different. Many areas of the visual cortex and the brain that are thought to be involved in the colour processing (Roland & Guly, 1994) are different, as well.

It is believed that 85% of people with autism saw colours with higher intensity than typically developed children (Turner, n.d.), children with autism might show superior visual discrimination (Riordan & Plaisted, 2001), and faster and more accurate target detection (Markram & Markram, 2010). Franklin et al. (2008) when testing yellow, red and green showed that children with autism were less accurate at detecting the differences between colours than children without autism.

Regarding colour preference, red seems to be the most preferred colour in neurotypical children; blue was the second preferred colour and then yellow, according to Zentner, (2001), Franklin et al. (Franklin & Sowden, 2008) and Grandgeorge et al. (2016). Children with autism also preferred red in the first place and blue in the second but would tend to avoid yellow and preferred green instead (Grandgeorge & Masataka, 2016). Results suggest that yellow might be avoided because of its luminance that could provoke hypersensitivity in children with autism.

Children with autism might show strong affinities to objects of particular colours. In the same way, children with autism might feel aversion from specific objects because of their colour (Heaton, Ludlow, & Roberson, 2007).

According to Denise Turner, anecdotic evidence suggests that, when applying colour in the built environment, white might be too overwhelming due to its intensity and brightness, green might be the safest (also suggested by Lynne Harrison), the colour red might make a child angry, and blue might be a de-stressor colour, with no reference to the colour yellow.

In terms of light, there is not much research about the influence of the colour of the light (and its different sources) on individuals with autism, either. What seems to be clear according to Temple Grandin (Thinking in images (Grandin, 1996)) and Andrew Brand (Living in the Community Housing Design for Adults with Autism (Brand, 2010), among others, is that the flicker and the buzz of fluorescent lighting might be detrimental for people with autism. These aspects of fluorescent light increase repetitive behaviour (Colman, Frankel, Ritvo, & Freeman, 1976), arousal (Baumeister & Forehand, 1974), hyperactivity (Ross & Ross, 1976), and cause migraines and/or epilepsy tantrums. For these reasons, fluorescent light is a not recommended source of light for people with autism. These recommendations suggest that not only the colour and properties of the light are important but also the source of production of light plays an important role, as well. Instead, it is recommended to use incandescent lights (Colman et al., 1976) or LED lights (Turner, n.d.). However, it has been proved that some LED light also may flicker if the power supply is not constant. Although the flicker of the Fluorescent light might be more aggressive than the flicker of the LED lights, as it has a flicker rate of 120Hz, compared to the 50-60hz that the LED might have, moreover, it is also recommended to avoid having shadows projected on the surface: shadows can be distracting and confusing.

Brightness can also be a detrimental factor for children with autism. Autistic individuals might have an abnormal pupillary light reflex which prevents the proper adaptation of the eye to changes in brightness, provoking migraines.

There is no more literature about the influence of the colour and source of the light in people with autism and its effects on mood and performance.

Colours can also help in the academic environment. Ludlow et al. (2006) found that by using transparent coloured overlays over printed texts, the speed of reading increased up to 35% in autistic individuals. Each participant selected the overlay colour that perceived best improved the clarity of the text (among nine coloured and one grey overlays). There was not the most popular colour chosen by the participants. This fact shows that the presence of colour seemed to improve the academic performance, but the different election of colours across the participants emphasises the idiosyncrasy of the individuals.

As previously seen in Section 2, light is a universal architectural factor than can have a significant influence on typically developed people's behaviour, performance and mood. However, there is no scientific evidence about how the colour and the light affect children with autism's mood, performance and behaviour.

Biologically speaking, it is broadly known that people with autism, thus people with SPD, do not perceive the environment as neuro-typical people are considered to do (e.g. Robertson and Baron-cohen 2017; Baranek et al. 2007). This factor suggests that the features of the environment might have a different impact on the body responses and mood of those who perceive the environment differently.

Two studies, Knez et al. (2001) and Kuijsters et al. (2015) suggested that the colour of the light does not affect everybody the same way, and indicated that age could be an essential factor.

Sleegers et al. (2012) also highlighted how vital the light could be in the behaviour and performance of vulnerable individuals such as children in the academic environment. Could light also help children with autism to perform better in the academic environment?

Moreover, psychologically speaking, many intrapersonal, contextual and cultural factors can influence the colour influence.

Do children with autism have already assimilated cultural associations, as expected with neuro-typical children or adults? Or do children with ASD associate other meanings to colours which do not relate to the cultural context and more related to the close social context? How can we understand the psychological associations that people with autism link to colour?

Does the colour of the light influence people with autism at a biological level or psychological level?

Can the mood of children with severe autism be interpreted, and later improved with thoughtfully designed spaces and light conditions?

2.5. Research question

As seen in Section 2 from this chapter, Sleegers et al. (2012) showed how important light could be for children in the academic environment. If the intensity and colour of the light can help to improve concentration, boost motivation and change the mood in neuro-typical children, what would be the influence of the light in people – like children with autism – who absorb the stimuli from the environment more deeply? Could light improve their mood when they feel sad and frustrated? Could it make them relax when they feel stressed? Could the light soothe the anxieties of children with autism? If the light could guide their behaviour and mood, would people with autism be more integrated into society?

To sum up, could a change in the colour of light change the mood of children with autism?

Although a few recommendations based on anecdotal evidence exist about how a space for people with autism should be, no academic publications came to light about the perception of the colours of the light and their influence in children with autism's mood. Further research is required to understand better the relationship between children with autism and the environment to be able to create sensory accessible buildings for them.

While it has been broadly accepted that newly designed buildings need to be physically accessible for everybody, little attention has been drawn to the sensory accessibility, a matter of vital importance. After reviewing the literature about the influence of the colour and source of the light in mood and performance, a gap in the literature was identified. While most of the papers took for granted the individual and consider that everyone would similarly perceive the environment, some of the literature also emphasises that factors such as their psychological associations, gender or age, among others, might influence their perception of the environment, as well.

For this reason, focusing the attention on individuals who present brain differences and learning disabilities and perceive the environment profoundly differently compared to neurotypical people, such as people with severe autism who cannot express on their own, and suffer from SPD, was crucial to give them a voice and develop a method to understand how the environment can impact on their body responses and emotional reactions, thus, their mood (as defined for this thesis in Section 5.1 on Chapter Five). Therefore, the primary purpose of the present research is to create a method that could inform about how children with autism perceive the colour and source of the light individually and how they influence their mood. Hopefully, knowing this information, accessible sensory solutions could be designed, and their quality of life could be improved.

CHAPTER THREE - METHOD

3.1 Introduction

The literature review, presented in the previous chapter, revealed that the environment and its different characteristics have a strong impact on the behaviour, mood, productivity, health and well-being of those who experience them. Colour and light are two features of the environment that can influence the physiological measures and mood of the individual substantially, and the literature suggests that both can be applied in the environment to achieve certain outcomes for the person's well-being, mood and performance. Nevertheless, previous work did not take into consideration those who have different neuronal structures and suffer from sensory processing disorders (SPD) such as people with autism.

People with Autistic Spectrum Disorder (ASD) perceive the environment differently from neurotypical people, and design solutions or therapies based on findings from previous work about colour and light might not be as useful for them as these findings might be for neurotypical individuals.

Children with autism are especially affected by their surroundings, and the detrimental relationship with the built environment and the adverse outcomes that result from this relationship impede proper academic learning and enhance health and mood difficulties. For this reason, designing a method to understand how people with severe autism perceive the environment is crucial.

As previously seen in Chapter Two, when the influence of some factor of the environment, such as the colour of the light, is studied, researchers face the challenge by adopting different approaches.

One of the approaches consists of analysing the performance of the participants when they are exposed to certain stimuli in the environment (Baron & Rea, 1992; Knez, 1995; Mills et al., 2007; Sleegers et al., 2012; Soldat et al., 1997). This way, the researchers can evaluate whether the stimuli can boost productivity, concentration, creativity or good cognitive performance.

Another approach is to expose the participants to certain stimuli and ask them to evaluate their arousal and emotional valence (positive or negative tendency of the feeling) subjectively by using questionnaires (Elliot et al., 2007; Goldstein, 1942; Knez, 1995; Kuijsters, Redi, Ruyter, & Heynderickx, 2015; Küller et al., 2009; Suk & Irtel, 2010b; Valdez & Mehrabian, 1994). This approach is typically used when psychologists need to evaluate the emotional state of the participants, and the positive or negative influence of the stimuli.

A third approach is to combine subjective evaluations with objective physiological signals or with the evaluation of performance (Jacobs K. W. & Hurstmyer, 1974; Kwallek et al., 1996; Wilms & Oberfeld, 2016; Yoto et al., 2007). This approach is used by researchers to correlate objective measures such as physiological signals, to an emotional state, and then compare the results and evaluate the positive or negative influence of the stimuli in the participant and its correlation.

There are other approaches that only focus on the physiological responses of the participant, to evaluate body responses in relation to a stimulus (Ali, 1972; Caldwell & Jones, 1984; Gerard, 1958; Jacobs K. W.& Hurstmyer, 1974; Wilson, 1966). Others focus on careful observation to interpret the influence of a stimulus in a person's well-being (Ulrich, 1991). These approaches do not provide information such as emotional state or emotional valence.

As far as it has been possible to ascertain, no previous research about the influence of the colour of the light has relied only on physiological signals and behavioural responses, without the use of self-report questionnaires, to inform emotional states. However, as previously seen in Chapter Two, tools like subjective questionnaires might not be used with children with severe autism who cannot interpret their reactions and cannot answer the questions. For this reason, an approach that only focuses on physiological signals was adopted. As the need is to understand the influence on a participant's mood responses, it is necessary to devise a way to link the physiological results with potential changes in mood, and such a method was created for this experiment.

As this is a raw area of research because no research has been done about creating a method that will allow to measure the influence of colour and light on the physiological signals and thus the mood of children with autism of by only using empathetic tools, there is a need to determine many matters. For example, it is crucial to know what sort of data would be suitable for understanding the peculiarities of every individual and their way to perceive light, how the experiments should be designed to collect the necessary data without interfering in the performance of the child, who would be suitable as a participant in such a study, and where should the experimental procedure take place, among other questions. In other words, as no previous research has been done about this topic, it is necessary to design a method for tackling this matter and to find out what is going on in terms of the perception of colour and light by children with autism and its influence on physiological signals and mood.

Some kind of replicable study is necessary and will need to be performed under controlled conditions, and objective measures will need to be collected to inform us about the difference in perception of the colour of light and its influence on mood.

This chapter discusses the experimental method pursued to answer the key questions of the study with a straightforward structure. First of all, the chapter explains the method proposed. Secondly, this chapter focuses on the participants, children with severe autism, and the proper environment where the experiments take place. As previously seen in the literature (Chapter Two), the context plays a significant role in the routines and performance of children with autism. Thirdly, the equipment used for creating different light ambiences, the equipment used to collect the physiological data (electrodermal activity (EDA) and thermography) and behavioural data (rate per minute of tics), as well as the experimental installation is presented in detail in this chapter. Finally, the experimental procedure and its peculiarities are explained.

The innovative method proposed in this chapter attempted to (1) interpret how the physiological signals and behavioural analysis differ with different stimuli and also (2) to see the way people with autism and other cognitive disabilities perceive the environment by using only objective data and objectively identifying changes in the emotional state that each individual might feel under certain conditions by combining the different body responses. The combination of the body responses is displayed in a three-dimensional map explained in Chapter Six, the 3D Mood Box.

It is fundamental to mention that, as discussed in Chapter 2, there is very little work in this area and none in the detailed questions being pursued in the present research; therefore, the design of this study had to be developed from first principles. This study is the first of its kind examining colour and source light perception and its influence on the mood in children with severe autism using only physiological signals.

3.2. Method proposed:

One of the main goals of this study was to create a method to show whether the colour and source of light could influence the mood of people with sensory processing disorder (SPD) such as children with autism or not; and, in the affirmative case, show how the lighting affects them.

It was expected that the light would influence the body responses and mood of people with autism as it does with neurotypical people (see Section 2, Chapter Two). However, SPD can affect every person with autism very differently; therefore, the perception of the light and, for instance, the impact of the lighting on the mood of the participants, could result in the same light having a different impact on the mood of different people. Although differences in psychological associations, age or gender between individuals also can influence the perception of the environment, the difference in perception is likely to be enhanced for people with SPD because this condition makes them more sensitive to such sensorial differences.

For this reason, the purpose of this study is to investigate whether it is possible to design a method to understand how changes in light affect a person with autism and to explore what this would require in terms of both data collection and analysis, and not explore whether any particular effect might apply to the population as a whole. This study, therefore, aims to inform how it might be possible to detect and interpret the differences in physiological signals, behavioural responses and mood in a person depending on the colour and source of the light in their immediate environment, thus showing the possibility of creating bespoke lighting solutions to enable them to feel more comfortable in the future. To be able to achieve this, a significant amount of physiological and behavioural information would be needed to understand the way each participant interacts with the environment and its stimuli – in this case, in the form of the colour and source of the light.

To understand how the colour and source of the light affect children with autism's mood, the matter is going to be tackled by performing a case study composed by a series of sessions (14 in total, two per week during seven weeks) in which four children with severe autism (see

Section 3.3.) will experience six-light conditions: four LED lights (yellow, green, red and blue Light) and two different sources of light (white LED and fluorescent light) (see Section 3.5 and 3.6.). The experimental setup was composed of the participant, the caregiver, the technical support and the primary researcher (myself). The technical support was there in the event of equipment failure.

In order to make the children feel like home and peaceful, the sessions will take place in their school, a familiar place for them (Section 3.3.). Therefore, all the equipment necessary will be installed in a controlled room located in the school, instead of a laboratory. The equipment consisted in a lighting system (see Section 3.5.) to control the different light conditions (see Section 3.6.), the tools that will be used to gather the physiological information (electrodermal activity and thermography) and the cameras to record their behavioural responses, and a set of laptops to control the whole procedure (see Section 3.7).

The first session will serve as a trial session so the participants can get used to the dynamic of the sessions. In the sessions, the participants will be playing with toys that they previously selected. Allowing the children to choose the toys will help them to engage the sessions more time than usual and will ensure that the children feel content during the sessions by playing with familiar toys. Reducing the level of anxiety of the participants was crucial to obtain objective results (see Section 3.9).

In the meantime, the light will change three times (unless the participant asks for more changes in the light, a fact that can provide information in its own, as well). The participants will be exposed to a different three-light sequence in every session, so the participants do not expect any light in particular, and their reactions are spontaneous (see Section 3.8).

During the session, the participants will be monitored with non-invasive empathetic tools such as EDA sensors (see Section 3.7.1.) attached to their foot and will be photographed with a thermal camera every 30 seconds (see Section 3.7.2), which will provide physiological information of the participants such as the skin conductance (arousal) and the temperature of the tip of the nose. These physiological signals will inform about instinctive body responses under different light conditions. This information, combined with the analysis of the repetitive behaviours on video recordings (see Section 3.7.3), will be analysed to see differences in body responses to the light stimuli and their mood.

Without simplifying the importance of the intrapersonal and cultural context of each individual, this research intends, by crossing the three-body responses which are linked to the parasympathetic nervous system, thus, to the interpretation of the brain of the different light stimuli, to evaluate their emotional states under different light conditions with no subjective and emotional ratings (Chapter Six and Chapter Seven).

This study does not intend to look into how the light affects the population with autism but to how the colour and source of the light affects these four individuals who have severe autism. For this reason, special attention will be drawn to the specific characteristics of every participant that can influence the perception of the light differently, such as the medical information and preferences (see Section 3.3).

This method is expected to shed light about how our participants perceive the different types of light and how these lights affect, not only their physiological signals but also their mood, by using non-invasive tools and collecting only objective data. A proper understanding of how these participants are affected by the light could help architects, designers and therapists to use proper lighting design solutions to enhance positive feelings and to improve their quality of life.

3.3. Recruiting participants:

As previously mentioned in Chapter Two sensory processing disorders can affect every person with autism very differently, and their perception of the light and, for instance, the impact of the lighting on their mood, could be different for each individual.

In order to understand how every participant was affected by the colour and source of the light, a significant amount of physiological and behavioural information was needed concerning each participant.

Therefore, having a vast sample size was not necessary but also not realistic because it would have increased the duration of the research dramatically and would not have permitted analysing the amount of data needed in the period given. As providing a generalisation of the results was not the purpose, a small sample size allowed the collection of a more significant amount of physiological information for each participant and, for instance, getting more person-specific results. This was enough to observe if the method succeeded on obtaining valuable information about the reactions and emotions of the participant. In other words, a small sample size of participants permits a much more prolific sample of physiological and sensorial data for each person, and to be able to link these data to the participant’s responses in a more specific way that would be possible for a larger number of participants. This methodological approach emphasises, works with, and seeks to understand the importance of the idiosyncrasy of each participant rather than the comparison between participants on the autistic spectrum. So how many participants would be necessary for this research? As pointed out in the literature review (Chapter Two), no prior studies about the influence of light on the physiological signals thus the mood have been carried out before with children with autism, so it was not possible to propose a sample size based on previous work or a methodology already used. Therefore, it was necessary to perform a pilot project that might inform a more in-depth study and the characteristics of it.

The first step was to contact organisations that might be interested in collaborating on the project, and that could provide a secure database of participants suitable for the study.

Prior's Court School is a registered non-profit making charity, which manages a specialist residential school for young people affected by moderate and severe autism aged 5-25 in Thatcham, in the United Kingdom. This Charity expressed an interest in the topic when it was approached at an early stage of the research. The management team of the school not only offered their facilities to conduct the research but also provided participants for the study who attend the school.

The participants belong to a vulnerable group because, first, they were children and young people and, second, they were people with learning disabilities and cognitive impairments. As the research was considered to involve more than minimal risk due to the vulnerable nature of the participants, ethical approval was necessary. Inviting people from 16 years old and over who cannot make decisions required the approval from a RED operating under the National Research Ethics Service, increasing the time for each application (pilot study and case study) considerably. For this reason, the students who were 16 years old or older were excluded from the sample.

The experimental design was accepted by the UCL Research Ethics Committee (Project ID Number: 9317/002, Appendix A). Participants met certain specific criteria. The participants needed to be:

1. students of Prior's Court School and be familiarised with their environment and the caregivers and therapists of the school,
2. between 8 and 16 years old,
3. diagnosed with autism and affected by sensory processing disorder,
4. not suffering from any visual impairment.

As the research is not about the condition of autism but about testing a method to identify responses to changes in the colour of light, the pathologies of participants are not relevant to this study. The students who attend Prior's Court school are categorised in three different groups depending on the individual risk rating, which determines the level of support they receive from the Psychology department. These groups are Green, Amber and Red. The Green group is for children and young adults whose behaviour is consistent and calm and friendly. Students in the Amber group are children whose behaviour is considered worrying and not predictable: sometimes they are calm, and at other times their behaviour might be challenging. Students in the Red group are children who need constant assistance from qualified carers all the time because of the high frequency of incidents. Their behaviour is challenging, and they can be aggressive both to others and to themselves.

After reducing the sample for age reasons, all the students who belong to the Red Group were discarded.

After applying these filters, the legal guardians of the potential participants were informed about the research (Appendix B and C). After informing all the parents of the suitable participants about the study, twelve signed consent forms were submitted.

These twelve students were included in the pilot project to check whether they were suitable for further research or not. In the first session of the pilot study, three participants were excluded because they experienced high stress and anxiety levels and, sometimes, aggressive behaviour during the first session of the pilot study. Finally, nine children (eight males and one female) participated in the pilot, which consisted of four sessions for each participant experiencing different types of light while they played with different toys.

During the pilot sessions, the participants were wearing sensors to monitor their skin conductance. The sensors were put on a wristband to ease the movement but, unfortunately, the sensors detached constantly, and these measurements could not be used for the analysis of arousal from the pilot. Therefore, the analysis mainly focused on careful observation of their behaviour during the sessions, which was recorded with video cameras and collected in video files. Special attention was drawn to the repetitive behaviour and number of tics the participants had under the different light conditions and to the attention span of the participants by analysing their visual behaviour and how long the participants looked at the activity without being distracted by other things of the environment. Both behaviours were analysed with Observer XT software. Although the measures of attention span were not entirely reliable because the therapists intervened and interacted with the participants often, influencing the data, the rate per minute of tics seemed to be an interesting feature for two reasons. First of all, it was a non-invasive way to evaluate behaviour that did not impede the children behaving normally. Secondly, the tics were, in most of the cases, very easy to identify, although they were different between the participants. The analysis of tics also showed high anxiety levels even when it was not evident that the participants were stressed. For example, due to the analysis of the repetitive behaviour, a peak of anxiety was identified in one of the four days, consistently across all the participants. The reason why the peak of anxiety was experienced that day was that the teachers were dressed up as literary characters. This fact went unnoticed by the researchers, and assumed as inoffensive for the students, thus not worthy of attention or to mention by the therapists. It was not until the anxiety peak was observed in the results that all the activities and events that could influence the behaviour and mood of the participants that happened before the sessions were analysed. Finally, the event was identified as a cause of the peak of repetitive behaviour and the higher levels of anxiety across the participants. Participants who showed more obvious repetitive behaviour were more keen to participate in a more prolonged experiment because they were easy to identify; therefore, the analysis of the level of anxiety could be more carefully done.

It also was essential to identify who seemed to enjoy the different activities, and who was able to seat down doing activities for the longest time. Some participants did not engage enough time and wanted to leave after a few minutes, impeding collecting enough information to register constancy through the sessions. The participants who enjoyed the activities and wanted to stay longer were more suitable to participate in a more extensive study.

It also was noted the participants who were more keen to wear the sensors. Some of the participants did not want to wear the sensors, and they had to be excluded from the final selection as the analysis of the skin conductance was relevant to inform anxiety levels and mood.

Finally, after reviewing the data obtained, the easiness to collect the information and the predisposition of the children, four children (three male and one female) were selected to participate in this case study. These four children were the ones who enjoyed the sessions the more, and for the longest time, who were more predisposed to wear empathetic tools such as skin conductance sensors on the skin, the ones whose nervous tics were easier to identify.

The participants received nicknames, specified below. From now on, the participants will be referenced by their nicknames for privacy reasons, and so the future discussions are easier to follow. The phenotypes of the students, including their health and autistic profile, which could be useful for future research and further discussion, are in Appendix E. The participants who participated in the case study were:

- Participant F; 15-year-old female. Non-verbal.
- Participant FX: 13-year-old male. Verbal with echolalia.
- Participant H: 13-year-old male. 50% verbal, and 50% uses communication software to support his use of spoken language.
- Participant J: 15-year-old male. Verbal.

The vital context of the participant, the phenotypes of the participants, the properties of the environment are factors that have to be taken into consideration because they can influence the results significantly. For this reason, in this study, all these variables were taken into consideration and noted for future discussion.

3.4. Environment:

The collaboration with Prior's Court enabled us to access one of the most sophisticated facilities for people with autism within the UK. This environment helped to know first-hand the student's routines at home and the school. The routines of people with autism are crucial to the welfare of these individuals. The knowledge of these habits is vital to bear in mind as many variables as possible. This control will allow us to understand better their reactions and preferences. As mentioned in Chapter Two, it is vital to understand the vital context of the participants to understand the influence of the colour of the light. Having access to their environment was extremely useful to do so. Figure 3.1 shows Prior's Court School.

Figure 3. 1. Prior's Court School.

It was essential to carry out the pilot and the case study in facilities of the school because the children would feel more comfortable in a familiar place and, this way, the likelihood of generating additional anxiety in the participants was minimised.

The sessions of the case study (and the pilot study which preceded it) took place in the therapy room of Prior's Court. The room was a plain room with no windows and no distractions such as decoration items or shelves with objects or books. The absence of windows permitted reasonable control of the lighting conditions within the space and reduced unpredictable and uncontrollable distractions from the views. The absence of decorative objects permitted to control the environment as much as possible. The perception of the colour of the light is not only dependent on the qualities of the light but also on the other coloured objects of the environment that might change the perception of the light. Moreover, as we needed to add some electronic devices into the room, if the room had distractions, it would have created too much of a sensation of a bustling place to work for children with sensory processing disorders. This room was provided with a table where the activities took place, six chairs and a chest of drawers. Figure 3.2 shows the basic layout of the therapy room of Prior's Court School and the location of the people involved in the sessions: R1 and R2 represent the location of the researchers. P represents the location of the participant. T1, T2 and T3 represent the location of the therapists who accompanied the participant. T1 is the therapist who leads the session, as indicated in Section 3.7. The layout of the lighting system is shown in Figure 3.4.

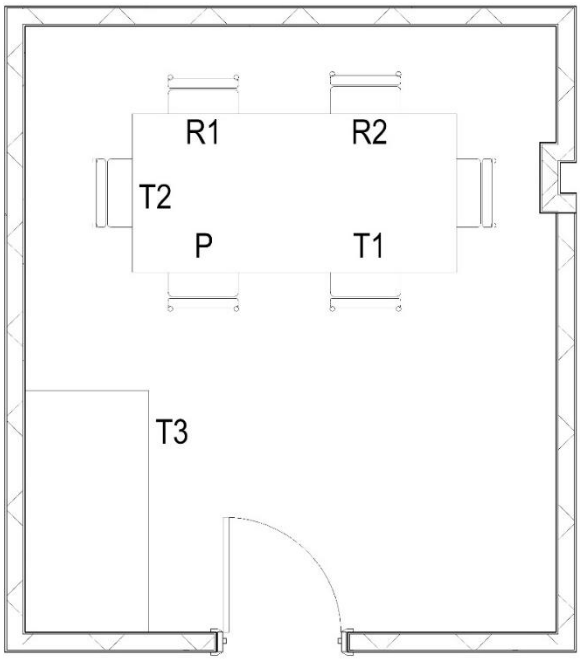

Figure 3. 2. Basic layout of the therapy room of Prior's Court School.

3.5. Lighting system:

The characteristics of the therapy room were ideal for adding all the essential devices of the study without overstimulating the space. The room needed to be as plain as possible because other colours in the room (e.g. the walls) might also affect the perception of the colour. The fewer distractions and objects the environment has, the more controlled will be the light conditions. As the conditions of the light had to be highly controlled, the fluorescent system already installed in the school could not be used, and a specially designed lighting system was installed in the room. This system enabled the properties of the light to be carefully selected and the different light conditions controlled by the researchers from their control location, on the table (see Figure 3.2).

First of all, this study aimed to inform about the influence of the colour of the light on the mood of people with autism. However, therapists and caregivers, like many testimonies collected for this research from the workers at the school, pointed out that the source of the light might also be essential. They expressed their concerns about fluorescent light and its influence on the health and performance of the people and, especially, those with ASD and SPD. As mentioned in Chapter Two, it is believed that the flicker and the buzz of the fluorescent light systems induce headaches and other health problems. For this reason, the influence of different sources of light on the mood of people with ASD was also a matter of interest in this case study.

In order to recreate all the light conditions needed, a lighting system was designed and created. The lighting system included both LED lighting and fluorescent lighting. The LED light can reproduce a vast range of colours and intensities and enabled enormous flexibility in creating ambiences.

The lighting system consisted of three lamps located in three corners of the room (see Figure 3.4). Each lamp consisted of a floor lamp with a specially designed system with two sockets, one for the LED bulb, which was wireless bulb from Philips Hue, and the other for the Fluorescent bulb. Both bulbs were covered by a lampshade covering made with a translucent white paper whose function was threefold. First, it had the function of diffusing the light from the bulbs around the therapy room. Secondly, the covering did not allow the participants to see the bulb directly, avoiding glare and discomfort. Third, both lights needed to be located in the same structure in such a way that the participant could not know if the source of the light was LED or Fluorescent light. The drawback of the diffusor was that it could reduce the effect of the flicker of the fluorescent light. For this reason, there was no translucent material at the bottom and top of the lampshade covering, so that the participants could perceive the possible flicker from the open faces of the diffusor (see Figure 3.3.).

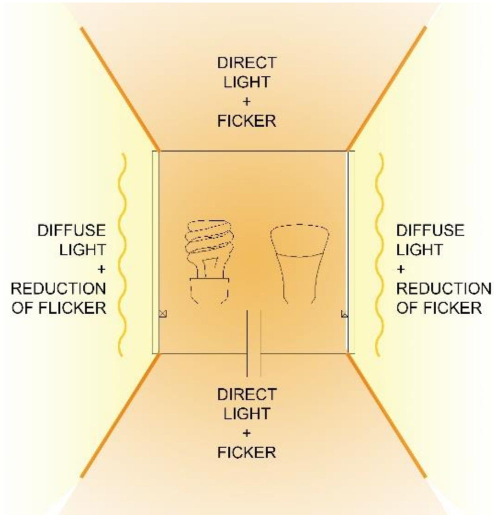

Figure 3. 3. Diffusor of the lamps proposed for the case study, which is only covered in four of their facets and uncovered on the top and the bottom of the covering.

The three lamps were connected to a wiring system that allowed the researchers to manipulate the lights from their seats. Moreover, the LED bulbs were connected to the WIFI, allowing and facilitating the changes of the colour of the light using the “Hue Lights” version v.3.4 app from a smartphone model Apple iPhone 7, operating system iOS (unknown software version). One of the most significant benefits from the Philips Hue LED system is to have the possibility to create bespoke light conditions in many different dimensions: hue, intensity, colour temperature and saturation. The fluorescent light could not be controlled in this way, and so was turned on and off by flicking a previously installed independent switch. Figure 3.4. shows the lighting system composed by the fluorescent light circuit and the LED light circuit, and its location in the room.

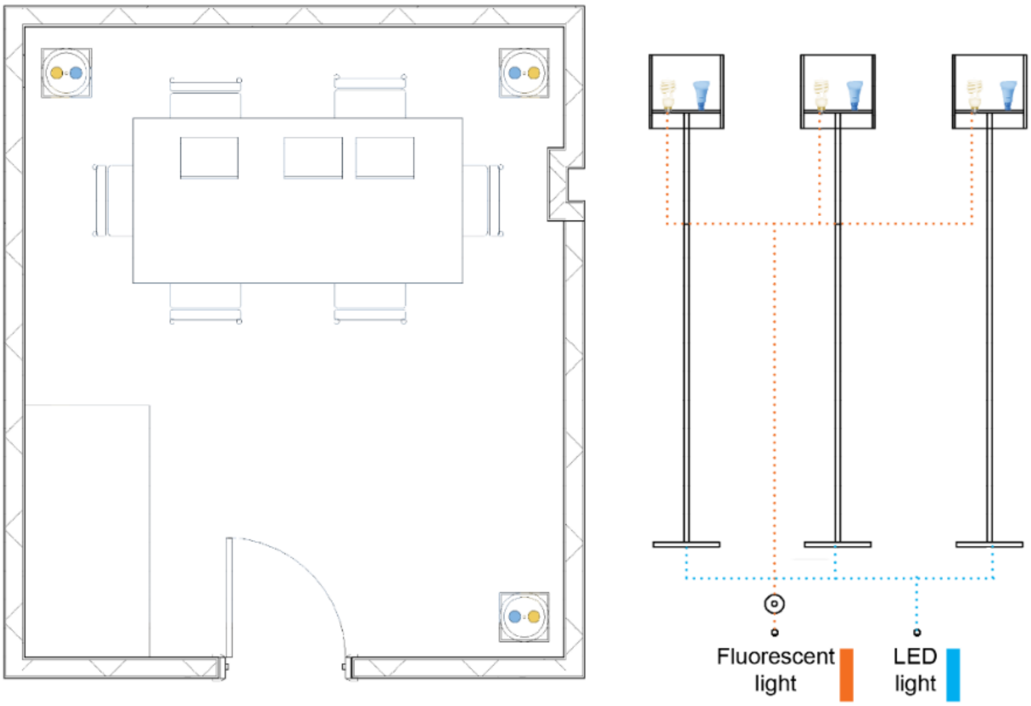

Figure 3. 4. Lighting system installed in the therapy room of Prior's Court School.

As seen at the beginning of this Section 3.2, the case study had two primary goals: first, to evaluate the influence that the different sources of light might have in the behaviour, body responses and mood of the participants; and secondly, to evaluate the influence that the colour of the light might have in the behaviour, body responses and mood of the participants.

The impact on mood, physiological signals and behaviour of different sources of light was approached by comparing the reactions of the participants under white fluorescent and white LED light conditions. The white LED bulbs were configured to recreate, as nearly as possible, the same hue and intensity of the fluorescent bulbs (the properties of both lights are specified in Section 3.6). Although it would have been interesting to study the influence of the fluorescent light installations of the school to see the real effects on the students, it was not possible to replicate these with the same light properties of colour temperature and intensity in the LED bulbs. For this reason, the lighting system of the school as a whole was not studied.

The impact of the different colours of the light (yellow, green, red and blue) was approached by using LED bulbs that could recreate as many colours and properties as needed.

3.6. Properties of the lights studied:

As seen in Chapter Two, many researchers previously failed to control the different properties of the light (i.e. hue, saturation and intensity), not bearing in mind that any alteration of these properties might lead to different results. For this reason, results from studies which did not control these properties might not be generalisable to all tones of the same light and colour. Moreover, researchers trying to reproduce the methodology used in these studies which did not control the properties might conclude with different results after using lights and colour with different properties (Wilms & Oberfeld, 2016). For the present case study, three properties of the light (hue, saturation and intensity) have been noted and controlled. However, due to schedule limitations, not many combinations of the properties could be investigated, therefore, the only property which varied across the experiment was the hue, thus the wavelength of the light in the visible spectrum of the light. Saturation and intensity were kept constant across all the LED lights throughout the experiment.

For the purposes of this thesis, every time any light used for this study is mentioned, it will be referenced by the names below, considering these names always linked to the properties mentioned in this chapter. Figures 3.5 to 3.10 show the different light conditions that the participants experienced during the experiment. There were six different light conditions studied, and they were:

1. White or (W):

   Source: LED light

   Configuration of the bulb: Colour Temperature: 6535K. Intensity: 100% 254/254.

   Mired: 0% 153/500

   Average illuminance on the table due to the three lamps: 46.2 lux

Figure 3. 5. Therapy room under White light.

2. Fluorescent light or (F):

   Source: Fluorescent Light

   Configuration of the bulb: Colour Temperature: 6400K. Intensity: 100%.

   Average illuminance on the table due to the three lamps: 45 lux

Figure 3. 6. Therapy room under Fluorescent light.

3. Yellow or (Y):

   Source: LED light

   Configuration of the bulb: Hue: 15% 9630/65535. Intensity: 100% 254/254. Saturation:

   60% 152/254

   Average illuminance on the table due to the three lamps: 33.1 lux

Figure 3. 7. Therapy room under Yellow light.

4. Green or (G):

    Source: LED light

    Configuration of the bulb: Hue: 35% 23136/65535. Intensity: 100% 254/254.

    Saturation: 59% 151/254

    Average illuminance on the table due to the three lamps: 12.1 lux

Figure 3. 8. Therapy room under Green light.

5. Red or (R):

    Source: LED light

    Configuration of the bulb: Hue: 0% 0/65535. Intensity: 100% 254/254. Saturation: 59% 151/254

    Average illuminance on the table due to the three lamps: 22 lux

Figure 3. 9. Therapy room under Red light.

6. Blue or (B):

    Source: LED light

    Configuration of the bulb: Hue: 60% 39410/65535. Intensity: 100% 254/254.

    Saturation: 59% 151/254

    Average illuminance on the table due to the three lamps: 17.4 lux

Figure 3. 10. Therapy room under Blue light.

The parameters of the lights were kept constant, so any light was on, it was always the same. For example, if Red is mentioned in the text or R, is mentioned in the graphs and figures, it is always the same kind of red, except when deliberately tested changes in hue or saturation under participants' command, although in these cases, they will also be mentioned and indicated with the symbol (+).

Even though researchers stated the importance of controlling the three properties and parameters of the light (hue, saturation and intensity), there is one property of the environment which is a consequence of the light that went unnoticed by Wilms et al. (2016): the illuminance (lux). This property might be relevant as the perception of the environment and the activities can vary because of it. However, it was not possible to equalise the level of illuminance that impacts on the surface of the table with all the different lights because that would have compromised the other three parameters of the light.

The different values of illuminance between the White and Fluorescent light might be imperceptible, as the receptivity of light in the eye is logarithmic and receptivity increases sharply from 0 to about 5lux, but then the increase tails off so that the difference between 40lux and 50lux is almost imperceptible. However, it is important to bear in mind that the lower values of illuminance obtained under Green Light, for example, could affect the perception of the colour and its influence in the mood and behaviour of a person.

Nevertheless, the illuminance is a factor challenging to control. The illuminance on the table could vary depending on the toys which were on the table or close to it due to its reflection. Nevertheless, even though the values can be inaccurate or cannot be used in the analysis, illuminance was considered and noted for future discussion, and as a guideline for future work and possible replications of the study.

The colour preferences of the participants were not considered because in the pilot only two of the four participants managed to respond whether they liked the colour or not, and one of the two who did respond did not seem to understand the question, so his answers were not reliable. As it was difficult to obtain this information, it was excluded from the analysis. Therefore, it will not be possible to compare preference ratings with EDA responses to see if these results align with those of Day and Sobol (1967) who stated that there is a relation between EDA and colour preference, or contrarily, with those of Gerard (1958) and Wilms et al. (2016), who proposed that EDA responses are not related to colour preference.

3.7. Equipment:

Analysing the impact of the colour of the light on people's behaviour, body responses or/and mood has been done many times before (Ali, 1972; Gerard, 1958; Keith W Jacobs, 1972; Kwallek et al., 1996; Suk & Irtel, 2010a; Valdez & Mehrabian, 1994; Wilms & Oberfeld, 2016; Wilson, 1966; Yoto et al., 2007), but no study has been carried out with people with severe autism. Commonly, the influence of the light on people's emotions or behaviour has been analysed through self-report questionnaires (Kuijsters, Redi, Ruyter, Seuntiens, et al., 2015) or evaluating the performance of the participants doing cognitive tasks (Elliot et al., 2007). However, reactions of children with severe autism cannot be analysed in the same way. These participants are non-verbal and have learning disabilities and cognitive impairments, which impede their ability to answer questionnaires or doing similar cognitive tasks.

For this reason, it was necessary to rely on physiological data and behavioural analysis to get accurate information. As only one signal seemed to be insufficient to elucidate the emotional state of a participant, three different signals were collected to complement each other. The three different approaches were to analyse the electrodermal activity, the thermography and the behavioural analysis through the video recordings.

3.7.1. Shimmer3 GSR+ Units - EDA sensors:

Electrodermal activity (EDA), also known as Galvanic Skin Response (GSR), and as described in detail in Chapter Five (Section 5.2), is used to obtain data on the autonomic changes in the electrical properties of the skin from the variations of sweat which come from the sweat glands. As the sympathetic nervous system controls sweating, EDA is associated with emotional and cognitive processing and is an essential and objective variable in psychological science. EDA measures changes in arousal and can inform cognitive states and emotions such as stress, excitement and fear, among others (S. D. Kreibig, 2009). EDA is also used as an indicator of concentration, as demanding tasks provoke increased EDA responses (Novak et al., 2010).

The electrodermal activity was measured with wireless Shimmer3 GSR+ Units. A Shimmer3 unit consists of the unit, two electrodes which measure skin conductance (EDA) and a third electrode to measure the Heart Rate. Figure 3.11 shows the wireless Shimmer 3 GSR+ Units with the two skin conductance sensors used to monitor the arousal and the electrodermal activity of the participants. However, for this case study, the electrode which measures the heart rate was not used. This device works under a frequency of 128.0Hz and also allows capturing Photoplethysmography (PPG), 3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer and integrated altimeter.

Figure 3. 11. Wireless Shimmer3 GSR+ Units with two skin conductance sensors attached to two electrodes.

Skin conductance, acceleration and rotation were calculated in real-time by Consensys PRO v1.5.0 software, but only the skin conductance signals were taken into account for this case study. Acceleration and rotation signals were only used in case of dubious skin conductance signals to double-check if any abnormality on the data was due to the movement of the participant or other possible reasons.

Avoiding noise and dubious skin conductance was crucial. The participants needed to use their hands during the experiment to perform their activities, so the sensors were placed on the arch of the foot, considered one of the more recommendable places to measure EDA due to the high quantity of sweat glands located in this area (Dooren, 2011). Figure 3.12 shows the exact two points where the sensors were located in the arch of the foot to collect the electrodermal activity required. Placing the two sensors in the arch of the foot was less disturbing and less invasive for the participants than other suggested places such as the palm of the hands, fingers or wrist, as we could see in the pilot study. On the one hand, the pilot study showed that placing the sensors on the hand was too invasive, so the participants could not perform the activities well and were distracted and stressed by the sensors. On the other hand, placing the sensors on the wrist was not convenient because the sensors detached from the wrist often due to the movement and the data was too noisy to be interpreted and used.

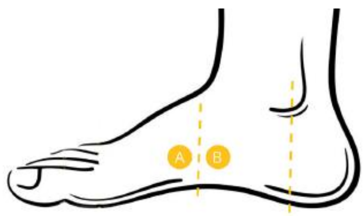

Figure 3. 12. Location where the Shimmer3 GSR+ sensors were placed (A and B), without touching each other, to avoid noisy signals.

The therapists added into the routine of the participants the event of putting on the sensors right after the participant said hello to the people of the room. Adding events like this one in the routine of children with autism helps to soothe their anxieties due to unexpected events during the session. The therapist, with the help of the researcher, put the sensors always in the same place of the arc of the foot. The participant started playing with toys right after it was checked that the sensors were well attached, and the quality of the skin conductance signal was correct.
After checking that the signal was being recorded correctly, the clock started counting. After 15 minutes, the therapists stopped the gaming and requested the participants to take the sensors off.

EDA is a very accurate measure, but the interpretation of the results extracted from the arousal can be contradictory and misleading. An increase in arousal might indicate either excitement or fear, for this reason, it is necessary to take a secondary signal in order to make sense as a signal in isolation is meaningless unless there is something that only occurs in one or the other condition. This could be a change in, e.g. local blood pressure at the extremities in which a decrease might indicate fear, and the increase might indicate excitement, or local skin temperature in which a decrease of the temperature of the tip of the nose might indicate fear, and an increase of it, excitement. Thermography was selected due to its non-invasivity.

3.7.2. Compact thermal camera FLIR C3 Pocket size – Thermography:

The temperature of the skin brings essential information about nonverbal behaviour, which is not subject to subjective interpretations. Thermal imaging of the face appears to be a non-invasive promising tool for the study of the spontaneous responses to emotions (Merla et al., 2007), as will be explained in-depth in Chapter Five (Section 5.3).
The main point of the study of the body in the study is the tip of the nose. The nose, particularly, the tip, proved to be the best place of the body to record changes related to emotional and cognitive states for many reasons. First, the most dramatic changes in temperature due to emotional and cognitive states have been recorded on the tip of the nose, the forehead and the sinuses (Merla et al., 2007; Salazar-López et al., 2014). Secondly, the nose is a straightforward point to target when it is necessary to evaluate the temperature at a consistent point. Temperature measurements from bigger parts of the body like the forehead might present a larger target area than a point such as

the nose, and the data can vary a lot if the studied point is not always the same. Measuring the tip of the nose might be more accurate than other parts of the body, so, for this reason, it was the spot chosen for the case study.

No evidence was found in the literature of thermal imaging being used before in studies to evaluate the influence of the light in mood or behaviour. However, as it is a tool that can inform about the responses from the sympathetic system, such as stress and anxiety, it was included to supplement EDA.

The camera used for the study was a compact thermal camera FLIR C3 Pocket size. It is a camera with a high-sensitivity detector (<0.10°C) which captures subtle changes in temperature at the scale of a pixel, which can be observed in real-time as well as being streamed video over USB. The camera has an IR sensor, and every picture is configured in JPEG format, with 4800 individual thermal measurements that can be analysed and edit with the software FLIR tools. The range object temperature that this camera captures is from –10°C to +50°C, and the image frequency is 9 Hz. Figure 3.13 shows an image of the thermal camera FLIR C3 Pocket used for this experiment. The parameters used for the pictures were:

- Emissivity: 0.95
- Refl. Temp. 20°C
- Distance: 1m
- Atmospheric temp.: 20°C
- Ext. Optics temp.: 20°C
- Ext. optics trans.: 1
- Relative humidity: 50%

Figure 3. 13.FLIR C3 Pocket size thermal camera.

The camera was secured to a tripod, and after 30 seconds the clock started counting, the researchers took pictures manually of the face of the participants every 30 seconds, collecting a range of 30-32 picture for session and participant. Low-resolution images, pictures showing the participant moving agitatedly, blurred pictures and pictures showing something blocking the nasal area of the participant were removed from the dataset to avoid contaminated data.

FLIR Tools software was used to identify, export and analyse the points of interest of every picture (the tip of the nose).

3.7.3. Behaviour analysis - Video recording:

The room was equipped with three video cameras to record the sessions and the instinctive reactions and repetitive behaviour of the participants. Repetitive behaviour, as will be explained in-depth in Chapter Five (Section 5.4), can be a way to inform about anxiety or relax levels of the participants.

Figure 3.14 shows the location of the cameras in the therapy room. Two USB cameras (C1 and C2) were installed in the bars of the two foot-lamps in two opposite corners to record the whole environment and all possible movements. A third camera (C3) was installed on the table, in front of the participant to record their facial expressions. All the cameras were synchronised with three laptops located on the table with ManyCam software (L1, L2 and L3, see Figure 3.15). The cameras and video recordings were controlled and monitored by the researchers.

During the pilot study, the video recordings were vital to extract much information about the influence of the light on the children's behaviour. In the pilot study, the analysis included the sight behaviour (attention span) of the participants and the tics and reactions. While the sight behaviour only informed about the possible levels of concentration of the participant, the reactions and tics were much more informative and related to the mood of the participant.

The analysis of the videos was done with The Observer XT 14, focusing on the tics and reactions of the participants. In this software, every tic (divided into two sub-groups: motor tics and phonic tics) is identified and marked manually. The software calculates the rate per minute of tics under any condition in particular. In this case, the rate per minute of tics is calculated depending on the colour of the light when the tics take place.

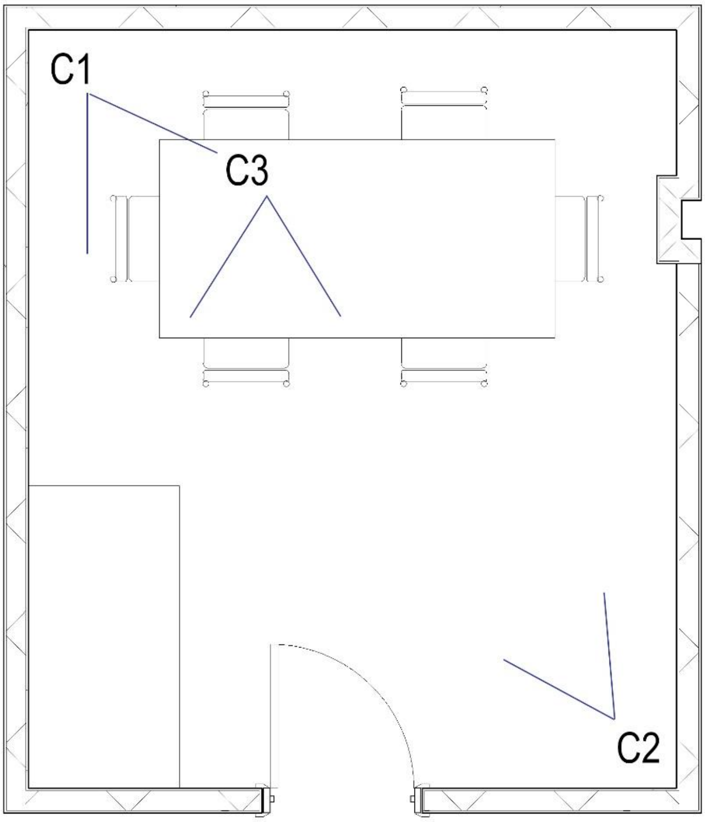

Figure 3. 14. Location of the three USB cameras installed in the Therapy room.

3.7.4. Other devices:

Finally, more equipment was necessary to complement the various devices in order to control the lighting and sensor systems and to record the physiological signals as previously mentioned in Section 3.6.1 and Section 3.6.2 of the participants, and their behaviour, as previously seen in Section 3.6.3.

This complementary equipment was composed of three laptops located on the table and controlled by the researchers and a smartphone, connected to the WIFI of the school from which the researchers controlled the lighting system by the Philips Hue App.

Figure 3.15 shows the therapy room and all the equipment used for this case study and mentioned during this chapter.

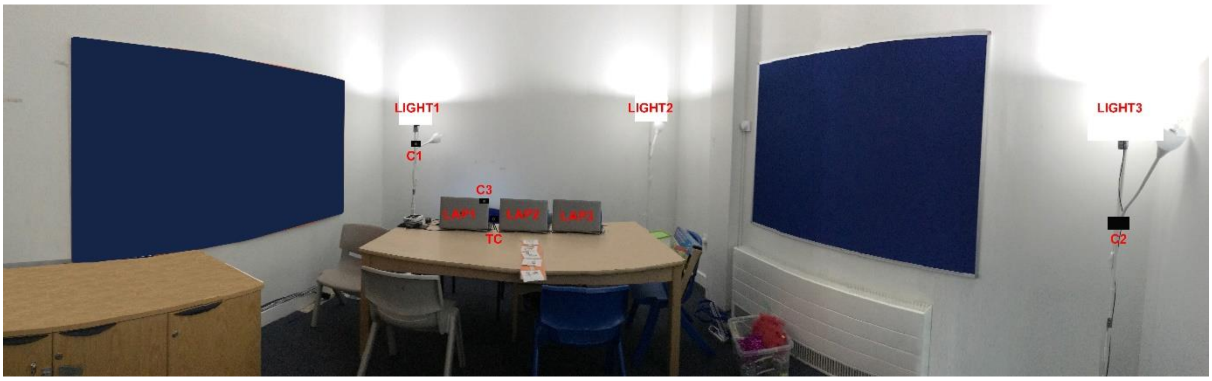

Figure 3. 15. Therapy room equipped with the equipment.

3.8. Lighting sequences:

In every session, after having the sensors on, and all the devices started recording and monitoring the participants, the participants were asked to play with their favourite toys while they were exposed to three different lights for 5 minutes each, so an experiment run lasted 15 minutes in total (without taking into consideration the set up and the tidying up phase).

Figure 3.16 shows the different sequences of three lights that were scheduled, making sure that every light was repeated at least six times. There were two sessions (Tuesday and Thursday) per week (W) during seven weeks (W1-W7).

The first session was considered as a trial session, and no lights were tested. The rest of the sessions started with a particular type of light and ended with another. There was no "standard" light that served as a baseline to start or finish the sessions because any kind of light would have provoked an effect on the participant that needed to be studied. Having this in mind, it would be interesting in future research to study the scope of the effect of the latest light (or the sequence of the three lights) on the participant. In this case, this could not be studied due to the difficulty to follow the track of the participants after the sessions.

	TUESDAY			THURSDAY		
W1	-	-	-	W	B	G
W2	Y	F	B	F	R	W
W3	B	Y	F	B	G	Y
W4	Y	G	R	F	Y	R
W5	G	F	Y	R	W	B
W6	F	R	G	G	W	F
W7	R	B	W	W	B	G

Figure 3. 16. Sequences of light used for the case study.

In the particular case a participant wanted to change the colour of the light, the light was changed for 30 seconds. After the 30 seconds, the previous light was turned on again, unless the participant insisted.

3.9. The sessions:

As already stated in Section 3.4, the sessions of the case study took place in the therapy room of Prior's Court School (See Figure 3.2), and there were two sessions per week for seven weeks. Fourteen sessions in total for each participant composed the full case study. The number of sessions proposed was calculated to observe a repetition of every light exposure at least six times. This amount of repetitions of the light exposures could be enough to observe consistency or not of the reactions under different light conditions. However, due to the particular condition of the participants, none of the participants could attend all the sessions. However, due to the particular condition of the participants, none of the participants could attend all the sessions.

Participants with severe autism present many different pathologies that impede them from being constant when performing an experiment or activity prolonged in time. It is important, as researchers, to design a method that permits them to be flexible with them, because the sessions can be stressful in certain moments and the experiment should never be a cause of anxiety for the participants. In addition, if the participants perform the experiments under different health conditions, the results of the experiment can be compromised. Participant F attended 13 sessions out of 14, Participant FX attended 14 sessions out of 14, Participant H attended 9 sessions out of 14, Participant J attended 12 sessions out of 14. Unfortunately, the broken sessions could not be replaced because of problems in the schedule of the school. The experiment was performed between school breaks, and after the experiment, all the students had to go home for the summer holiday., therefore, the sessions could not be repeated until September, one month and a half after the last sessions. Many different experiences - thus variables - would be added to the experiment that could compromise the results. Ideally, if possible, in future research the broken sessions should be repeated to obtain the more balanced information about the participants as possible.

The participants were always accompanied by, at least, one caregiver or therapist during the session.

The first session for each participant was considered as a trial session, and no physiological signals were recorded. As young people with autism are very susceptible to changes in routine, it was necessary a trial session to get used to the experimental process.

The rest of the sessions followed the following scheme:

First of all, the participant enters the room with a therapist. The first light of the session is already on, so the participant starts experiencing this particular light as soon as they enter the room. After entering the room, the therapists close the door to avoid the light, and other stimuli from the corridor contaminate the controlled stimulation from the therapy room.

When the participant enters the room, the researchers (R1 and R2), seated as indicated in Figure 3.2 from Section 3.4, turn on the thermal camera, which will be calibrated automatically during the first seconds of the session. Researchers also start recording with the three cameras, which are synchronised with ManyCam.

The participant seats on the chair in front of Researcher 1 (R1) as indicated in Figure 3.2, as well as therapists, do. Up to three therapists could accompany the participant. Therapist 1 (Figure 3.2) is the one who leads the session. Therapist 1 shows the participant the routine they will follow which consists of saying hello, taking their shoe off, putting on the sensors, choosing of different toys, playing with the toys, taking off the sensors, putting the shoe on and saying goodbye. Rigid routines might be essential, so people with severe autism perform and get used to new events.

The therapist asks the participant to take the shoe off and places the skin conductance Shimmer3 sensors on the arch of the foot of the participant. When the participant already has the sensors on their foot and is ready to choose a toy, the researcher starts recording on the laptop on the software Consensys Pro (Laptop 3). When the therapists and researchers agree that the sensors are correctly located and attached, the researcher starts the time watch. Every 30 seconds from then, one researcher takes a picture with the thermal camera, coordinated with the other researcher who clicks the event in Consensys PRO every time a picture is taken. Clicking these particular events allows synchronising the thermal signal to the EDA signal, which, later on, will also be synchronised with the tics on The Observer XT 14 software.

At minute 00:05:00, the researcher changes the light and clicks on the event associated with that light at Consensys Pro. At minute 00:10:00, the researcher changes the light and clicks on the event associated with that light at Consensys Pro. As indicated earlier, in the particular case where a participant wanted to change the colour of the light, the light was changed for 30 seconds. After these 30 seconds, the previous light was turned on again, unless the participant insists on having the light which (s)he requests.

At minute 00:13:00, the researcher warns the therapist that the session is about to finish in two more minutes. The therapist then warns the participant that the session is about to finish. This way, the participant can anticipate the events, and the end of the session is not too abrupt for them. At minute 00:15:00, the researcher tells the therapist to end the session.

When therapists and participants agree to end the session, the therapists take off the sensors from the participant's foot. As soon as the participant does not have the skin conductance sensors on them, researchers stop recording the EDA signal and taking pictures with the thermal camera. When the participant leaves, the researchers stop recording with ManyCam at the same time and switches off the thermal camera.

After every session, all the remarkable events that happened during the session are noted to inform the future analysis. Sometimes the results of one session might be more extreme than the results from others, and these annotations could untangle the reason for these differences.

3.10. Tasks:

The participants were asked to play with different toys during the sessions. These toys were chosen by the participant and were toys that the participants liked and were used to playing with them. The reason behind allowing the children to choose what they wanted to do was to make sure that the participants felt comfortable during the sessions, hence, the factors which could provoke anxiety were minimised and would not be mistaken with the anxiety or stress that the different lights could induce.

Every participant played with different toys which involved different levels of engagement, implication and performance. The different selection of toys was not problematic for the analysis because every participant was analysed individually.

Participant F spent the sessions watching song videos with the iPad. He combined three different toys every session and these toys were Car track, Penguins and Bricks. Participant H did not engage very well with the toys during the sessions, and he needed different stimuli every time. He seemed comfortable playing with bricks and doing puzzles. Participant J was also unpredictable, but he fancied playing with the toys. His selections were bricks, penguins, Car rack and iPad.

As every participant chose their toy every time, each participant was content about the activity selected. Ensuring that every participant was happy with the situation reduced the possibilities to encounter different levels of anxiety or distress between the sessions, easing the comparison of results between the sessions of the case study. It can be said that allowing the participants to choose the activities was sort of an emotional baseline for the participants.

3.11. Baseline tests

There were no baselines recorded for any participant for a primary reason. The case study focused on identifying different ways of perceiving the environment of each participant and how this is reflected in changes in physiological signals and mood according to the colour and source of the light proposed in the study. For this reason, there were no lighting conditions of reference to compare the data that were already considered as specifically calming or beneficial, not even the lighting system installed in the school facilities.

Moreover, the participants found it hard to engage with any activity more than 15/20 minutes due to their short attention span. As the sessions were limited, researchers needed to spend as much time as possible recording data for future analysis.

3.12. Control group

There was no control group because the main objective was to interpret the different ways of perception of the light of the four participants selected, and not to establish similarities with other groups, generalise the results after the analysis or do statistical analysis, therefore, the question of normative children is not relevant to the process of identifying the responses to the changes in the colour of light.

When researching with individuals with cognitive disabilities such as children with autism, it is necessary to match the study group with two control groups: one which matches with the study group chronologically, and other which matches in non-verbal cognition performance. Overall, the research would have required two control groups. Moreover, the sessions took place in the school were the children with autism study to reduce all the variables that could influence their stress levels, and to be able to understand the context of the participants correctly. Each of these control groups would need to have similar conditions to be able to compare the results. If the location were the same, the two control groups would be in an unfamiliar place. If they were in a familiar place, this place would be different from the therapy room used in the case study. It was not possible to replicate the conditions and to have all the participants in similar conditions.

The primary purpose of this research was to be able to create a method and understand the idiosyncrasy of four individuals with autism and how they perceived the different colours and sources of the light, influenced by environmental, contextual and social factors, and how these changes in perception would influence in their mood.

3.13. Chapter Inference

In order to see how the children perceived the different light conditions, a case study was designed, and an experimental setup was installed in Prior's Court School, a familiar environment for those who participated in the case study, and the sessions were performed by four participants with autism, aged between 13 and 15 years old. The purpose of the experimental design was aimed at answering the research question of the study and other sub-questions that arise from the central question: how the colour and the source of light affect the mood and body and behavioural responses of children with autism.

The case study took place in a controlled environment where there was installed a specially designed lighting system able to set both LED and Fluorescent lighting and different colours of the LED light. Throughout the experiments, physiological information such as EDA and temperature of the tip of the nose, as well as video recordings to later perform the repetitive behaviour analysis, were collected during a series of 13 sessions per participant. In every session, the participant experienced different light conditions while playing with their favourite toys.

The dataset collected was prepared for analysis, as will be described in the next chapter, Chapter Four.

CHAPTER FOUR - PREPARING THE DATA

4.1 Introduction

Previously in Chapter Three, the experimental procedure, the set-up of the lighting system, and the devices used to collect participant's physiological and behavioural measures were presented. This present chapter discusses the preparation and analysis of the data obtained.

As indicated previously in Chapter Two, most of the studies about the influence of the light on people's mood or behaviour showed the impact of the light either relying on different types of self-report questionnaires to evaluate the matter (Kuijsters, Redi, Ruyter, Seuntiens, et al., 2015) or evaluating the performance after doing cognitive tasks (Sleegers et al., 2012). However, due to the nature of the participants of this case study, children with severe autism, these methods were not a feasible option.

Children and young adults with severe autism, as outlined in Chapter Two, have learning and cognitive capabilities, which are different from those observed in other people, and which often present challenges that impede them from answering abstract questions about their feelings or auto-evaluate their reactions. Therefore, this research needs to rely on objective data solely that can be in-depth analysed.

This different approach, compared to previous work discussed in Chapter Two, added a challenge to the research. Physiological data needed to be collected but no previous studies which observed the change in mood and behaviour regarding the colour of the light on children with severe autism were found, not to mention studies using these specific tools combined. One example of data that could provide objective evidence of responses to changing environmental conditions is that produced by consequent physiological responses. The question then arises of which physiological responses should be analysed. The likelihood would be that, because of the complexity of the way that a human body responds to environmental stimuli, this would need to include a variety of different physiological responses. However, despite detailed searches of the literature, no previous studies analysing such data relating to the colour of light and children with severe autism could be identified. As a result, there is no indication from the literature about which responses to analyse, either uniquely or in combination. Work in the PAMELA facility at UCL has explored various responses to environmental stimuli (e.g. Cheng 2014; Wang 2017; Karekla 2016; Bainbridge et al. 2008, 2015). This work as involved both physical and physiological responses, both singularly and in combination, but none had worked with children with autism. Adhitya & Tyler (2019) shows the interpretation of this work as a whole in the form of an environmental response model, which proposes the pathways from the environment to the brain and, through physical and physiological responses, back to the environment. The research discussed in the present thesis follows a similar approach to this work, and extends it to children with autism, as well as incorporating additional physiological data streams and developing further the associated analysis methods.

The qualitative data base was composed of the videos recording the case study. The qualitative database was also composed of the interviews one-to-one with the carers, who provided personal information and past experience with the environment about the participants, as well as the preferences of the participants and the phenotypes and health diagnoses were collected before the case study and formed the qualitative database.

The quantitative data were exported from the electrodermal activity sensors (Shimmer3 GSR Kit) and the thermal camera (FLIR C3, FLIR Tools). The third kind of quantitative data was extracted from the software The Observer XT after careful observation of the video recordings identifying motor and phonic tics. All these three measures which composed the quantitative database were independently analysed in order to understand the different reactions of each participant during each session and lighting condition, and later synchronised to see the possible impact on the mood. These pieces of data constituted the quantitative database.

Thus the personal characteristics of every participant together with the participants' physiological and behavioural signals were brought together to obtain a deeper understanding of the effect of colour and source of the light in the body responses and mood of every participant, as the results did not intend to be collated across the group as a whole.

The process to develop the qualitative and quantitative databases, as well as the manipulation of the gathered data to transform it in structured and accessible data suitable for further analysis, are described next. The combination of the qualitative and quantitative databases collected for this research enabled the in-depth analysis of the different body reactions of every participant under different lighting. Figure 4.1 shows the database collected during the full case study, composed of different databases from every participant. For a detailed explanation of the information collected from every participant, see the example of Figure 4.2.

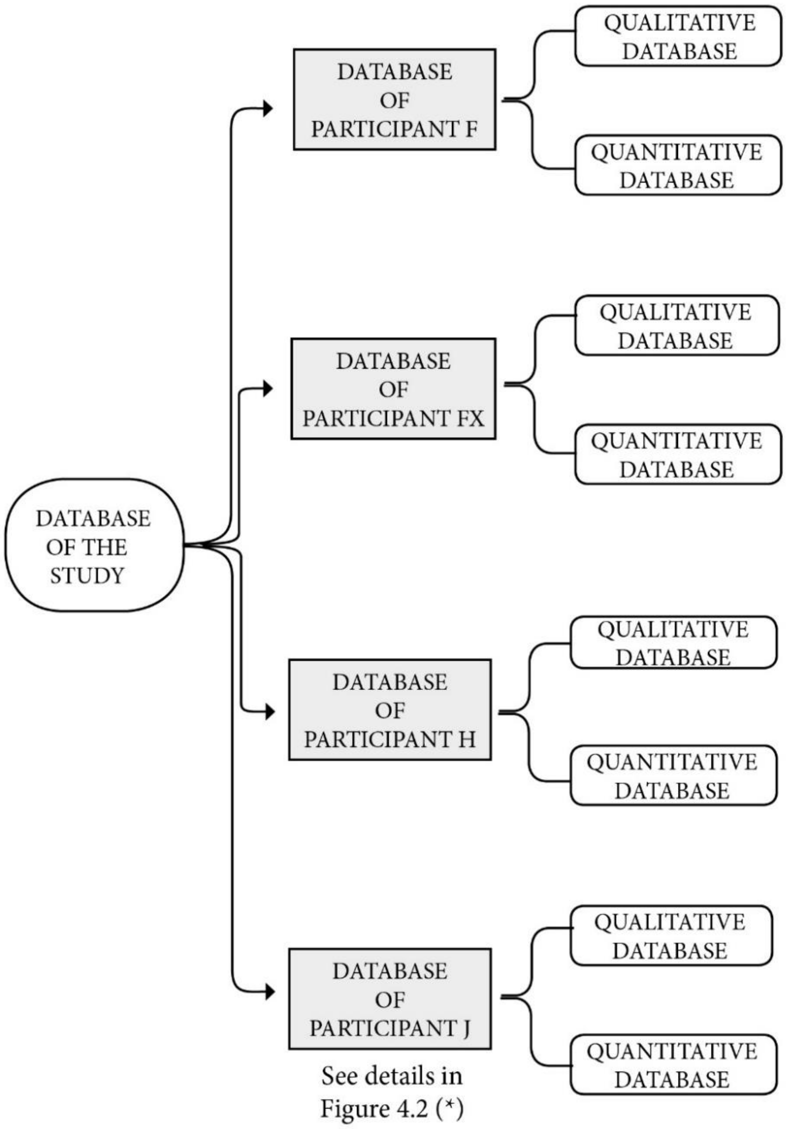

Figure 4. 1. Database collected during the full case study.

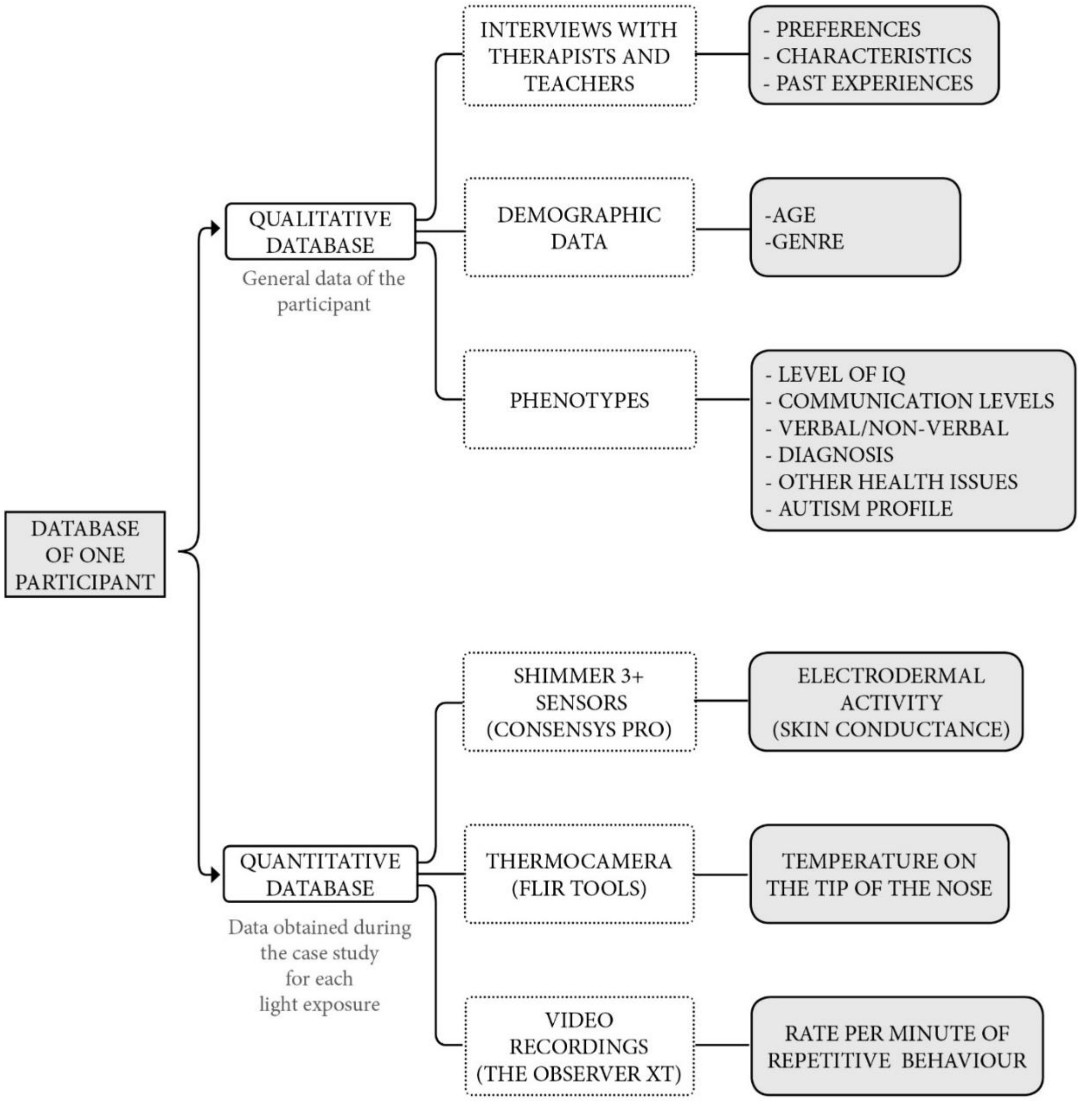

Figure 4. 2. Qualitative and quantitative database collected from every participant.

4.2 Qualitative database:

There are two forms of qualitative data relevant to this research: (1) qualitative data in medical records, such as phenotype data that help to define the nature of the participant, and (2) verbal data obtained in the form of questionnaire or interview processes, in which the participant is able to express their feelings about the experimental conditions being tested. The first type was obtained and used to triangulate and observe the validity of the method. In the present case, the second type is more complex because the participants were all unable to communicate verbally. For Type 2 qualitative data to be obtained, it is necessary for the participant to be able to communicate - i.e. to convey meaningful information to the researcher in relation to the questions/issues being discussed. None of the participants was able to do this. Only one could express any form of words, but these did not meet the Type 2 criterion of meaningful communication. Although psychologists and social workers might have methods of establishing communication with nonverbal vulnerable populations, therapists and carers from the school could not propose an appropriate form of communication to be able to interpret their feelings regarding the different colours of the light. In the pilot test performed before the experiment there was an attempt to obtain responses from the students to know whether they liked certain colours or not. To do so, there was used a method currently used in the academic facility which consists of giving the students cards with the colours and ask them to put the cards in a "like" board or "dislike" board. When trying to obtain responses from the students this way, it was obvious that the students did not understand the question or their responses were never consistent within the four days of the pilot study. Besides, it was not possible to know whether the students related the colours to the colours of the light, colours in general or whether the students associated the colour to other factors which were independent from the experiment. This fact highlighted the fact that the students who participated in the study were not able to communicate. However, as the purpose of this research is not dependent on the participant being able to communicate the research could continue using other methods to try to ascertain a better understanding of each participant's responses to the change in the colour of the light.

Therefore, this database was composed by, first, the information provided from the therapists prior (in one-to-one interviews which took place in the pilot study which preceded the case study) or during the case study about characteristics, experiences and preferences of the participants. Secondly, the qualitative database was also composed of video recordings of every participant during the different sessions and light conditions. These videos helped to reveal particular reactions and to increase understanding of the behaviour of every participant.

However, these videos were also used later to obtain quantitative data regarding the rate per minute of tics, as will be explained in Section 4.3.3.

4.2.1 Personal data:

The personal data, such as preferences of toys, and other personal particularities observed during the sessions of the case study (and the pilot which preceded it), were included in the database to understand better the reactions and the outcomes of the physiological analysis.

4.2.2 Demographic data:

The personal data, such as age and gender, were included in the database to understand better the reactions and the outcomes of the physiological analysis.

4.2.3 Phenotypes of the participants:

The phenotypes of the participants presented the mental, communication and health-related characteristics of the participants. The database was composed by the level of IQ, the level of communication, whether they were verbal or non-verbal, the diagnosis and other medical issues and the description of Autism Profile.

4.3 Quantitative database:

This database comprised the physiological information such as skin conductance and accelerometer, the temperature of the tip of the nose and the RPM of tics, of every participant during the different days and light conditions.

4.3.1 Electrodermal activity (EDA):

The electrodermal activity (see Chapter Three, Section 3.7.1; and Chapter Five Section 5.2) was measured to observe variations of arousal depending on the colour of the light as previously undertaken by Wilson (1966) and Jacobs and Hustmeyer (Jacobs K. W.& Hurstmyer, 1974), among others. It was recorded with a Shimmer3 GSR system (Chapter Three, Section 3.7.1), placing the sensors on the arch of the foot of every participant, as exposed in Chapter Three.

The software which supported the recordings was Consensys PRO v1.5.0. This software permitted live-streaming of the signals with a 128.0Hx frequency during the session and recorded the measurements on the system simultaneously. The live-streaming of the Skin Conductance graphs permitted continuous control of the quality of the signal and, if the quality of the signal became defective, it was possible to take action to relocate the sensors.

Consensys PRO software apart from recording the EDA allows live-marking of noteworthy events which happened during the sessions. During the sessions, any change of the colour and source of the light and every thermal picture taken was noted.

The Event Markers used for this case study were the different types of light and a marker for every thermal camera picture:

- White
- Fluorescent light
- Yellow
- Green
- Red
- Blue
- Thermal Picture

These markers enabled a straightforward synchronisation with the other physiological signals and eased a proper understanding of the body responses under different light conditions.

Once all the information was recorded, it was stored on the system in .csv format. All the Excel files were exported to MATLAB (version R2018b) for future analysis.

Before the EDA signals could be analysed, several preprocessing steps were applied. First, the inverse of the resistance signals was computed to obtain skin conductance. Second, flat segments of the signals due to loss of contact of the electrodes were automatically detected and removed. To fill these segments, a Piecewise Cubic Hermite Interpolating Polynomial method was used (which preserves some of the temporal characteristics of the signal). This considers the parts of the signal with good electrode contact to estimate the most likely signals during the poor-contact ones. Among the different methods, cubic interpolation was chosen because it helps to preserve the characteristic exponential decays of electrodermal responses. Third, a low-pass filter was applied to help attenuate high-frequency peaks associated with motion artefacts (noisy or faulty data provoked by different reasons such as abrupt movements of the participant or detached sensors from the skin, among others). In particular, an exponential smoothing algorithm (alpha = 0.01) was used as it is very time efficient and allows fast processing of large amounts of data. This method was successfully used in prior work (Thurston, Hernandez, Rio, & Torre, 2011), and the parameter was finely tuned to our dataset by visually examining the resulting signals. Finally, each of the session signals was normalised to be between 0 and 1 to help minimise baseline differences associated with individuals and sensor placement that can change from day-to-day. In order to do so, it was subtracted the minimum observed value to the skin conductance signal and then divided it by the new maximum value.

To assess the level of physiological arousal for each of the light exposures, the tonic level (SCL) and an average number of phasic peaks (SCRs) were extracted. The tonic level reflects slow physiological changes in the EDA response, and the number of phasic peaks reflects quicker changes associated with stimulus-specific or non-specific responses. Increase of both features is associated with increased physiological arousal (Boucsein, 2012). The variation of skin conductance is a relative measure, and the values can be different for different individuals. The goal is to look at variations of skin conductance, and variations of temperature of the tip of the nose (see Section 4.3.2) and variations on the RPM of tics (see Section 4.3.3), within the data of each participant to see if there is consistency in the results within an individual regarding the colour and source of the light.

To compute the features, each of the EDA signals was decomposed into its slow-changing tonic (SCL) and faster-changing phasic components (SCRs). Among the different methods, LEDALAB library developed by Benedek and Kaernbach was used (Benedek & Kaernbach, 2010). This approach captures the temporal dynamics of each of the components and extracts them following a deconvolutional approach. From the phasic component, the peaks were automatically detected with the MATLAB find-peak function (minimum peak height of 0.01, minimum peak distance of 5 seconds, and minimum peak dominance of 0.01). These parameters were selected based on prior work that analysed electrodermal changes in uncontrolled settings and finely tuned based on visual analyses of the resulting signals (Hernandez, 2015). Finally, the tonic EDA and the average number of phasic EDA peaks for each of the colour segments were extracted and analysed.
Figure 4.3 shows an example of the skin conductance graph obtained during the case study synchronised with three different main components: the light colour, accelerometer measurements and the time (Session 4, Participant J).

The first component is the skin conductance graph (the continuous line) displayed in three different colours. Every colour represents the different light was set during the data collection: the blue line represents Fluorescent light, the red line represents Red Light, and the black line represents White Light.

Below the continuous line of the skin conductance graph, there are two different dot-lines. As indicated in Figure 4.3, the sinuous dot-line that accompanies all the lower measurements of the skin conductance graph represent the tonic EDA (SCL) and the second dot-line with the pink squares represent the phasic EDA (SCRs). The pink squares are the number of peaks registered during the session.

The second component is the accelerometer graph below the skin conductance graph. The accelerometer graph shows the movement of the sensor during the session. As the sensors were placed on the foot, the graph shows the movement of the foot. The signal is composed of three lines (red, green and blue). Each of these lines shows the direction of the movement (axis X, Y or Z). The red blocks at the beginning and the end of the skin conductance graph correspond to the parts of the data which had to be erased for being faulty, which also coincide with sharp movements of the participant, showed in the accelerometer graph. This parts of the skin conductance graph which needed to be erased are the previously mentioned motion artefacts.

The third component is the timeline below the accelerometer signal. It eases synchronisation with the other physiological, and behavioural data also gathered during the case study (see Section 4.3.2 and 4.3.3).

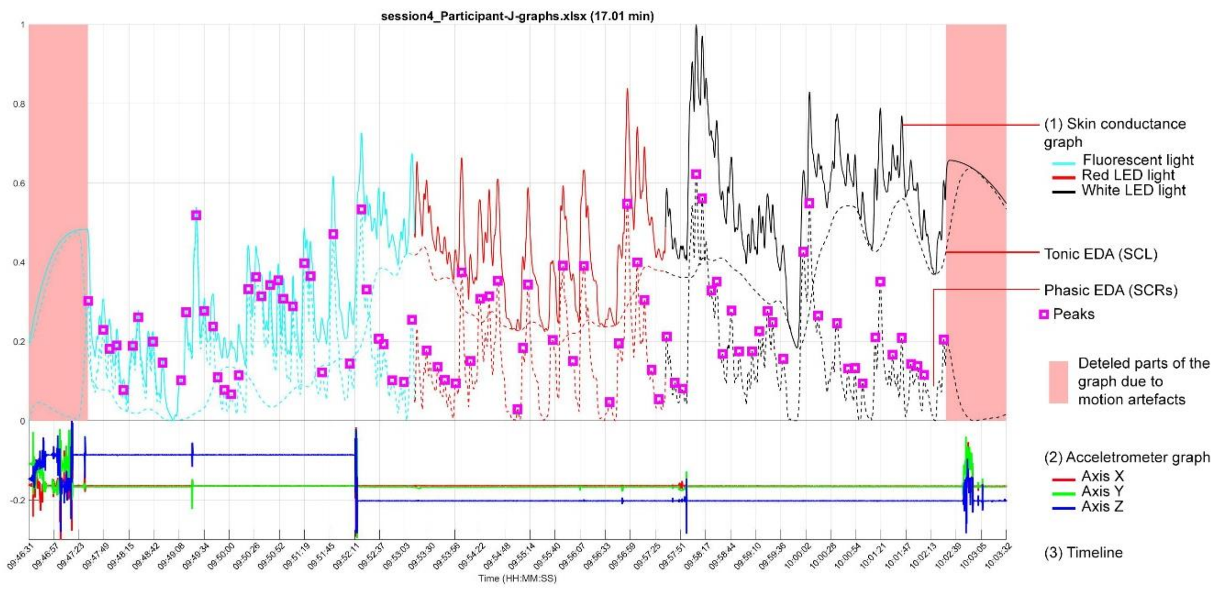

Figure 4. 3. Tonic EDA signal, phasic EDA, and accelerometer signal recorded in session 4 for Participant J under Fluorescent, Red and White Light.

4.3.2 Thermal Camera:

For this research, as explained previously in Chapter Three, in order to obtain temperature changes consistently at an easily identifiable point on the skin, the variations of temperature of the tip of the nose were targeted. The tip of the nose might be the most appropriate area of study not only because it is relatively easy to target, but also because a decrease of nasal temperature can indicate a trait associated with stress (Panasiti et al., 2016). In a "fight or flight response", blood rushes away from the outer layer of the body (for example, the nose) to fuel the muscles. For this reason, if measuring other parts of the body nearer the muscles, in the same stressful situation, measurements could show an increase instead of a decrease of temperature. Due to the location of this effect is in the tip of the nose, this phenomenon receives the name of Pinocchio effect (Moline et al., 2017). The implications of thermography are explained in more depth in Chapter Five (Section 5.3).

An average of 30 pictures was taken with the thermal camera from every participant in every session. The pictures were taken manually every 30 seconds, and the corresponding event marker was live-clicked on Consensys PRO software for ease of future synchronisation. After every session, all the pictures were imported from the thermal camera to the hard drive and the laptop.

The collection of the temperature measurements of the participants was done with FLIR Tools 2016. This software links every pixel of a picture taken with the thermal camera with the temperature registered on a particular point; in our case, the tip of the nose of the participant.

For this reason, it was imperative to discard all the pictures which could contain erroneous information: pictures (1) showing the participant moving agitatedly were discarded, as were (2) blurred pictures and (3) pictures in which something appeared to block the clear vision of the nasal area of the participant.

The remaining pictures were imported into FLIR Tools software for the later identification of the points of interest.

As mentioned before, the points of interest of the pictures were in the area of the tip of the nose and were clicked on the "Thermal Blending" option. The temperature in Celsius degrees was automatically calculated.

Figure 4.4 shows a thermal image showing the target area from which data were extracted. The temperature at this point can be observed on the right-hand side (33.9C).

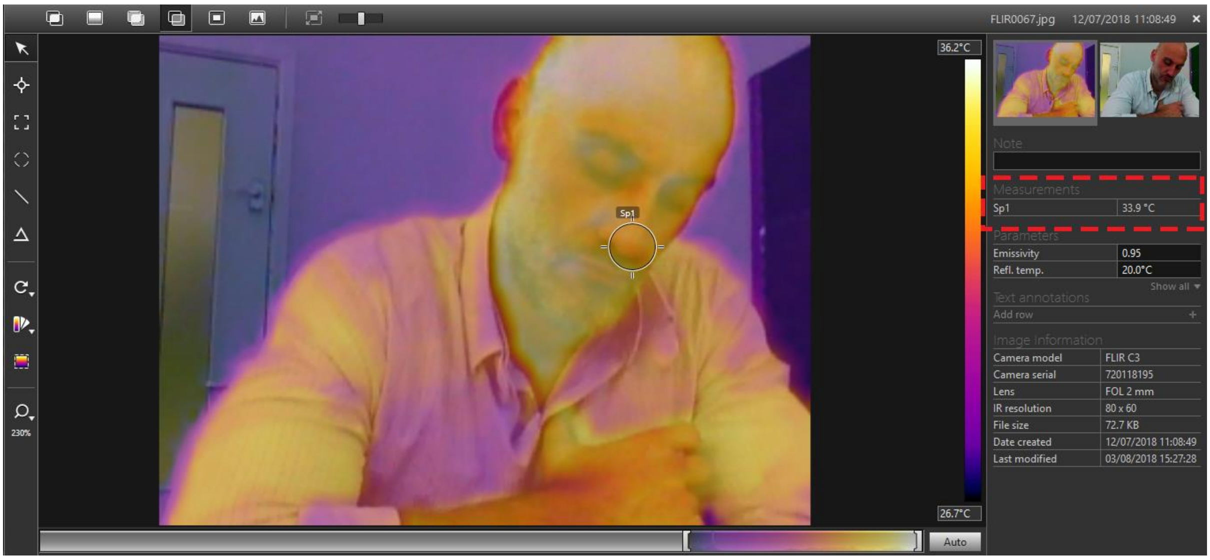

Figure 4. 4. FLIR Tools software selecting one pixel from the tip of the nose.

4.3.3. Observed data, the behavioural analysis and the RPM of tics:

As reported in Chapter Three, all the sessions were video recorded with three USB cameras. Two of the cameras were located in two opposite corners to record the whole room, and the third one was located in the table to record the facial expressions of the participants.

The video recording started when the participant entered the room and stopped when they left. However, only the recordings of the participants when they were already sat down on the chair, ready to start their sessions, were used for the identification of the tics.

The analysis was done using the software Observer XT 14. After identifying the different kinds of reactions that the participants could have during the sessions, a Coding Scheme was created about all the participants and the possible reactions to later mark manually every behaviour in the videos recorded during the sessions. The possible colours and source of the light were also added to the Coding Scheme, as well as a marker (Thermal PIC) which was marked every time a picture was taken with the thermal camera. The markers related to the lights and the thermal camera helped to synchronise all the data.

There were two kinds of behaviours and reactions: State Events and Point Events. State Events were the behaviours which could last several seconds and the beginning and the end needed to be marked manually. Point Events were short and quick behaviours. Figure 4.5 shows the markers used to identify the reactions of the participants in the software.

Behavior Name			Behavior Type
REACTIONS (Start-Stop)			
Covering the eyes	,	,	State Event
Talking to themselves	b	b	State Event
Distracted by the Thermal Camera	`		Point Event
Scratching their body	6	6	State Event
Bitting something of themselves	7		Point Event
Agressive Behaviour	8	8	State Event
Refusing to do something	9	9	State Event
Covering the ears	.	a	State Event
Asking for other light	-		Point Event
Singing	4	4	State Event
Repetitive verbal behaviour	3		Point Event
Stopped - blank	Z	Z	State Event
Repeating a particular sentence	X		Point Event
Putting the hand in mouth	Q	Q	State Event
Smiling	V	V	State Event
Head/Shoulder movement	M		Point Event
Dancing/swinging	D	D	State Event
Covering the toy	C	C	State Event
Shacking/dancing/swinging	N	N	State Event
Abrupt movement with the arm	A	A	State Event
Licking toy	L	L	State Event
Screaming	S	S	State Event
Shock face	F	F	State Event
Looking at the lights	R	R	State Event
wearing ear defenders	w	w	State Event
LIGHT ROOM (Mutually exclusive)			
WHITE LED	W	W	State Event
YELLOW LED	Y	Y	State Event
GREEN LED	G	G	State Event
RED LED	E	E	State Event
BLUE LED	B	B	State Event
WHITE FLUORESCENT	H	H	State Event
THERMAL PICTURES (Mutually exclusive)			
THERMAL PIC	T		Point Event

Figure 4. 5. Table showing the markers used to identify the reactions of the participants in The Observer XT 14 software. The first column shows the different kind of reactions observed and noted, second and third column show the coding to start and stop the behaviour and the fourth column show whether the behaviour is "State event" (prolonged in time) or "State event" (instant and sudden reaction which lasts shortly). After the colours of lights and the thermal camera pictures were included in the events, all the possible behaviours were also marked (See Figure 4.6).

Figure 4. 6. Reactions of Participant F observed and noted under Yellow, Fluorescent and Red light during one of the sessions of the case study. Every kind of reaction/behaviour has a colour associated for easier comprehension. These behavioural markers are also synchronised with the thermal pictures taken during the session and they are also synchronised with the light exposures experienced during the session..

Once all the possible behaviours were marked, these behaviours were studied in-depth and were divided into three possible categories of Point Events behaviours: motor tics, phonic tics and others. The difference between motor and phonic tics are explained in Chapter Five, Section 5.4. The category of "Others" refers to behaviours which might be less spontaneous, more consciously controlled by the participants, or reactions which respond to an apparent reason based on the context. For example, "looking at the lights" was considered in the section of "others" because it could indicate that the change of light was a visible stimulus as the behaviour was recorded at the same moment the light went on.

Another example that can be categorised under one category or another and needed profound observation of the context is "Repetitive behaviour". The fact that a participant repeats a sentence could be caused by several different reasons. If a participant repeats a sentence for no apparent reason, it will be considered a "Phonic tic". If, on the contrary, the participant repeats a sentence as a response to a question the therapist just asked, it will be considered as "Others". Figure 4.7 shows the reactions previously identified (Figure 4.6) divided into Motor and Phonic tics, and others.

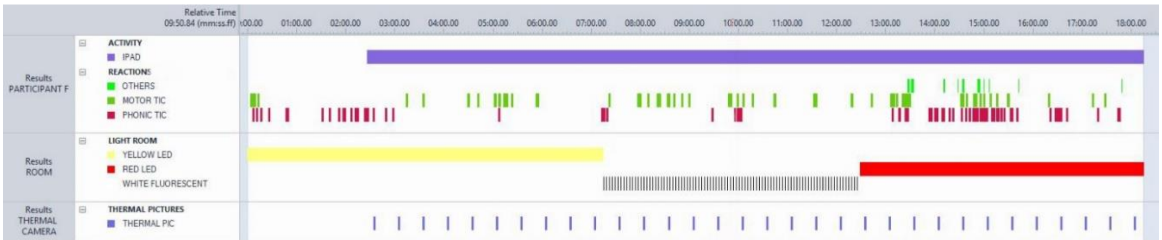

Figure 4. 7. Table showing Motor and Phonic tics and Others, observed for Participant F under Yellow, Fluorescent and Red light. These behavioural markers are also synchronised with the thermal pictures taken during the session and they are also synchronised with the light exposures experienced during the session.

The software Observer XT 14 allows Behaviour Analyses to be undertaken and the calculation of several remarkable data. The matter of interest for this case study was the duration of the various exposures of the lights during every session, the rate per minute of the appropriate behaviours (the motor and phonic tics) and the total number of reactions during the different light exposures. Figure 4.8 shows an example record of this data. The data is decomposed in the name of the session given during the analysis, the subject of participant the data is about, the behaviours experienced (motor tics, phonic tics, and others), the type of light and its duration, the rate per minute of the behaviours mentioned and the total number of the behaviours mentioned.

Sessions	Subjects	Behaviours	Total duration	Rate per minute (interval duration)	Percentage (interval duration)	Total number	Duration
F 04.	THERMAL CAMERA	THERMAL PIC	-	1.94272	-	10	17:07.92
F 04.	PARTICIPANT F	MOTOR TIC	-	8.74222	-	45	17:07.92
F 04.	PARTICIPANT F	PHONIC TIC	-	2.7198	-	14	17:07.92
F 04.	PARTICIPANT F	IPAD	05:08.85	0.194272	100	1	17:07.92
F 04.	PARTICIPANT F	OTHERS	00:12.81	1.74844	4.14677	9	17:07.92
F 05.	THERMAL CAMERA	THERMAL PIC	-	2.05625	-	12	18:02.16
F 05.	PARTICIPANT F	MOTOR TIC	-	4.28385	-	25	18:02.16
F 05.	PARTICIPANT F	PHONIC TIC	-	2.39896	-	14	18:02.16
F 05.	PARTICIPANT F	IPAD	05:50.15	0.171354	100	1	18:02.16
F 05.	PARTICIPANT F	OTHERS	00:04.49	0.514062	1.28301	3	18:02.16
F 08.	THERMAL CAMERA	THERMAL PIC	-	2.07474	-	12	18:15.79
F 08.	PARTICIPANT F	MOTOR TIC	-	4.66816	-	27	18:15.79
F 08.	PARTICIPANT F	PHONIC TIC	-	7.60737	-	44	18:15.79
F 08.	PARTICIPANT F	IPAD	05:47.03	0.172895	100	1	18:15.79
F 08.	PARTICIPANT F	OTHERS	00:19.65	1.72895	5.66162	10	18:15.79
F 09.	THERMAL CAMERA	THERMAL PIC	-	1.98246	-	10	17:43.41
F 09.	PARTICIPANT F	MOTOR TIC	-	3.96492	-	20	17:43.41
F 09.	PARTICIPANT F	PHONIC TIC	-	5.1544	-	26	17:43.41
F 09.	PARTICIPANT F	IPAD	05:02.65	0.198246	100	1	17:43.41
F 10.	THERMAL CAMERA	THERMAL PIC	-	1.50979	-	10	17:38.32
F 10.	PARTICIPANT F	MOTOR TIC	-	6.34114	-	42	17:38.32
F 10.	PARTICIPANT F	PHONIC TIC	-	4.68036	-	31	17:38.32
F 10.	PARTICIPANT F	IPAD	05:19.49	0.150979	80.3948	1	17:38.32
F 13.	THERMAL CAMERA	THERMAL PIC	-	1.55341	-	10	24:57.05
F 13.	PARTICIPANT F	MOTOR TIC	-	1.86409	-	12	24:57.05
F 13.	PARTICIPANT F	PHONIC TIC	-	4.66022	-	30	24:57.05
F 13.	PARTICIPANT F	IPAD	06:26.25	0.155341	100	1	24:57.05
F 13.	PARTICIPANT F	OTHERS	00:02.68	0.155341	0.694444	1	24:57.05

Figure 4. 8. Example of RPM of tics and other attributes calculated from The Observer XT 14 in Red light conditions. The first column indicates the Sessions of the case study, in this case F indicates the participant and the number indicates the day of the session. The second column shows the subjects to which the behaviours are attributed to. The third column indicates the type of behaviour. The fourth column is the total duration during the light exposure that the participant experienced each behaviour. The fifth column indicates the RPM of every behaviour considering the total duration of the light exposure and the total number of behaviours experienced (shown in the sixth column). The seventh column indicates the total duration of the session recorded.

The data of the repetitive behaviour and tics associated with the different colours and sources of light will show the variations of the RPM of tics and if these variations are relevant.

4.4. Individual analysis for every participant:

The analysis of all the physiological signals and behavioural analysis was done individually for each participant. First of all, it was observed whether the different factors studied tended to increase or decrease regarding the colour of the light within the same session. The daily analysis was very helpful for seeing the different influence of the colour and source of the light in the physiological signals because all the possible variables would remain the same within the day. When comparing results from different days, there might be many uncontrollable variables such as health problems, unexpected events before the session or a poor sleep pattern before the day of the session, among others, that could influence the results obtained from the physiological devices. For this reason, different physiological or behavioural measures obtained under different kinds of lights during the same session could indicate that the difference in temperature, for example, is due, in fact, to the different colour of the light, which is the main variable changing during the session.

Secondly, it was observed if the variations of the physiological signals were significant. Significance, in terms of EDA, was any alteration of the signal. In the case of temperature, variations of the temperature of the tip of the nose of fewer than 0.10 degrees Celsius were considered meaningless. Variations of less than one tic per minute were also considered meaningless.

Thirdly, it was observed whether the variations of the physiological and behavioural signals were consistent across the different sessions. This observation was challenging because there were no repetitions of the actual sequences of the different light colours and, as dealing with relative measures, the variations of the signals have significant meaning when compared to measures obtained in other light conditions which may vary severely across the days. For future research, it would be interesting to have more repetitions of the light sequences so the results might be easier to compare.

Sometimes, it is possible to observe similar patterns on the physiological measures during the different sessions, even though the light sequences were set diversely. The fact that a particular pattern was constant across the days, regardless of the colour or source of the light, could indicate that the variations of temperature might not be due to the light properties or, as indicated in Chapter Two, the order of the light set might play a significant role. The presence of these patterns can also be due to other reasons, such as the participants getting used to the session, being more focused with time, or a divergent approach to different activities, among other circumstances, which are difficult to control. For this reason, having more repetitions could help to elucidate whether the variations of physiological signals are, in fact, due to the light itself or, on the contrary, other variables. Unfortunately, the participants were not able to do more sessions that they did.

After the daily analysis was done, the average of the signals obtained during all the sessions under the different types of light was observed. The results could inform future therapies, and design solutions for each participant in the case that the variation observed were due to the properties of the light and not because of other variables.

4.4.1 The synchronisation of the data:

An efficient synchronisation of the data was crucial to interpreting the signals correctly. For this reason, the synchronisation started during the collection of the data stage.

As mentioned before in Section 4.3.1, Consensys PRO software permits live-marking of noteworthy events which happened during the sessions. During the sessions, any change of the colour and source of the light and every thermal picture taken was noted. These indicators were later easily synchronised with the videos, the thermal camera and the behavioural analysis.

Figure 4.9 shows the synchronised data: skin conductance (with its components SCL and SCRs), accelerometer signals, timeline, motor and phonic tics and the thermal camera pictures with values of the temperature of the tip of the nose. Figure 4.9 shows how the quantitative data obtained during one session is represented visually.

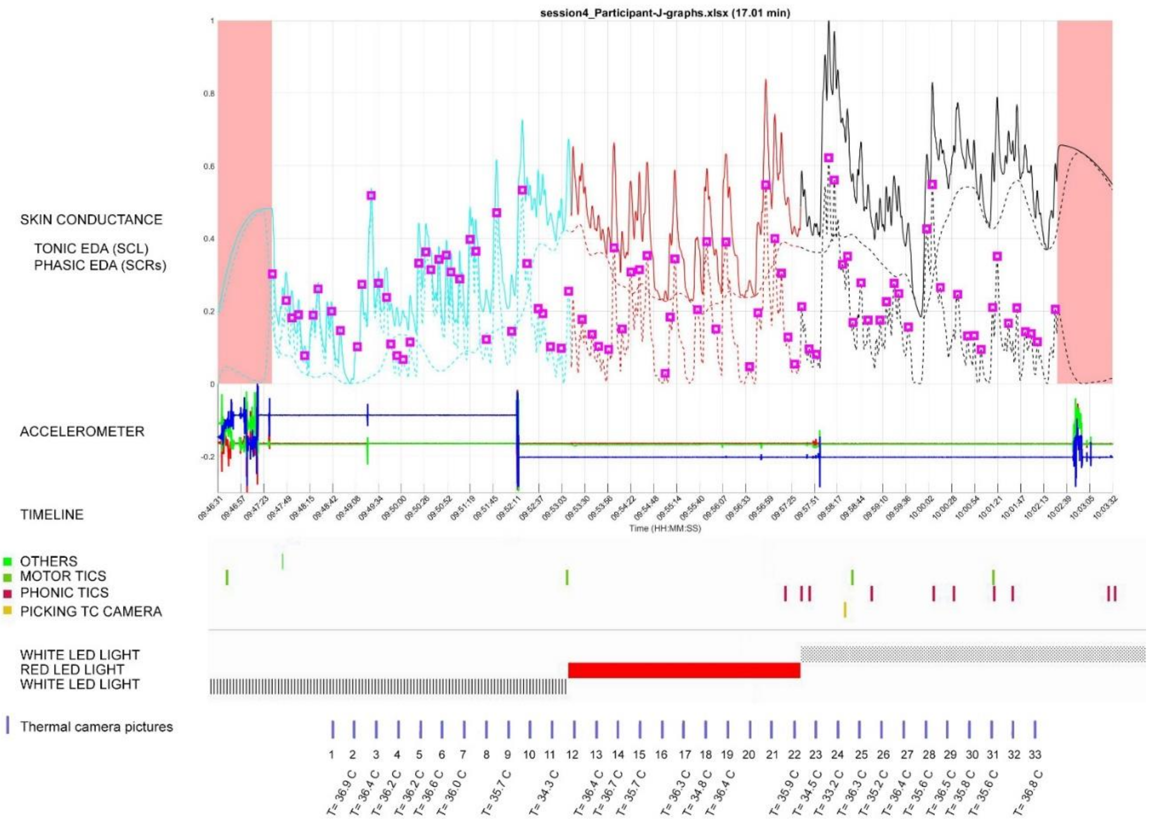

Figure 4. 9. Quantitative data collected during one session. The figure shows vertically different measures such as the skin conductance and its components tonic EDA and phasic EDA, accelerometer, repetitive behaviour and temperature of the tip of the nose. All of them are synchronised with the light exposure the participant was experiencing when the measurements took place.

4.5. Chapter Inference

This chapter presented the arrangement of the qualitative and quantitative data collected during the case study to facilitate a proper analysis.

The primary purpose of this case study was to understand in-depth the perception of the colour and source of the light, and its influence in mood, of the four children with ASD who collaborated in the study. For this reason, different kinds of data were collected to complement each other and create a sophisticated and rich database.

This chapter described the different steps followed until the final quantitative database was ready to be analysed and the steps taken to ease a quick and accurate synchronisation. All physiological and behaviour measurements were addressed differently accordingly to the kind of information.

Due to the nature of the participants, physiological and repetitive behaviour responses to the change of light were not identical for all participants. This shows that every participant needed their data to be addressed independently.

In the next chapter, the main attributes and previous work about the two physiological measures (EDA and facial thermography) and the repetitive behaviour responses are described before the results extracted for each measure are carefully presented for each participant individually in two different ways: first, analysis per day and, secondly, a summary of the responses all days.

CHAPTER FIVE - **RESULTS**

5.1. Introduction

The primary purpose of this thesis is to develop a method and design a tool to understand how the colour and the source of light might impact the mood of children with autism. As ‘mood’ is a highly personal and idiosyncratic characteristic, it is necessary to examine the process within individuals. There is no reason to assume that what applies to one individual in this respect applies to someone else, so there is no intention to attempt to generalise results across individuals. According to Daniel Nettle and Melissa Bateson, the term ‘mood’ – when used for scientific purposes- refers to relatively lasting affective states that emerge when a negative or positive experience in one environment or time period impacts on the way an individual or animal responds to subsequent events, suggesting that the mood has a crucial adaptive function (Nettle & Bateson, 2012).

For the purpose of this thesis, mood is defined and interpreted as an emotional state of the individual during a specific period of time, the period of time of each light exposure. The positive or negative valence of the emotional state or mood of the participant during every light exposure can be interpreted and identified when observing body responses linked to the parasympathetic system, such as the physiological and behavioural responses studied in this thesis (electrodermal activity, thermography of the tip of the nose and the rate per minute of repetitive behaviour). The combination of the physiological and behavioural measures can inform about the relative and instinct emotions that the participant might experience during a light exposure in particular, compared to the emotions experienced under other light conditions. These emotions can be positive or negative. It will be the nuances found in their physiological and behavioural responses which will indicate what kind of positive (i.e. excitement, relief, happiness and relaxation) or negative emotion (i.e. stress, anxiety, sadness, boredom) the participant was experiencing, thus, what kind of emotional state or mood the participant experienced under specific light conditions. Therefore, the emphasis is on establishing a method for understanding an individual's mood-response to changes in the lighting environment. Therefore, after collecting various physiological signals that could be informative about the influence of the colour and source of the light, as revealed in a participant when they experienced changes of light whilst playing with their favourite toys. Each physiological signal can only inform about a particular attribute of the total body responses under different light conditions, but the combination of these responses can indicate the emotional state and particular way of integrating the stimuli of the individual participant. In this chapter, the analysis of the physiological signals is explained and discussed individually before being combined to provide indications of each participant's emotional states in Chapter Six.

Chapter Four described the steps followed in the preparation of the different kinds of data collected to be later analysed and synchronised — each kind of data needed to be prepared differently. Overall, in the case study, four types of data were collected: (1) the qualitative data was composed by personal information from the participants obtained from the therapists, the quantitative database was composed by three sets of data such as (2) the skin conductance signals, (3) the measurements of the temperature of the tip of the nose and (4) the rate per minute of repetitive behaviour (tics) obtained after analysing the video recordings.

This chapter will show the trends and results obtained from each body response individually. In chapter Six, all the pieces of data will be combined to understand all the mood links that individual results hide.

Chapter Five is divided into four parts. The first three parts refer to the three different kinds of quantitative data. The first part explains electrodermal activity (EDA), the second part explains the thermography of the tip of the nose, and the third part explains the rate per minute of repetitive behaviour. The fourth part analyses the three kinds of physiological information across participants, showing possible consistency between signals.

The first three parts have the same structure. First of all, the physiological signal is defined showing prior work which could be relevant to the analysis of the data. Secondly, the results obtained from the particular physiological signal are shown about each participant, to identify the particular way an individual perceives the colours and source of the light. Results are first analysed by day, to see variations in responses during the same day and compared with results obtained on the other days, and secondly, the average of the results is also analysed, in order to show possible trends. It is vital to emphasise that significance is not an issue here, the important point is the existence of a variation on the physiological measures because this method does not intend to perform a statistical test. After these two sections, a conclusion is written for each participant. Finally, after explaining all the responses obtained, by day and on average, for each participant, the responses of the four participants are compared to see possible differences and similarities.

5.2 Electrodermal activity

Electrodermal activity (EDA) defines autonomic changes in the electrical properties of the skin getting the information from the variations of the sweat glands in the skin. T As pointed out in Chapter Three, the sympathetic nervous system controls sweating, so EDA is linked to emotional and cognitive processing and is an essential and objective variable in psychological science. EDA measures changes in arousal and can inform cognitive states and emotions such as stress, excitement and fear, among others. For this reason, EDA is used as an objective index of emotional states (Kreibig S. D., 2009). EDA is also used as an indicator of concentration, as demanding tasks provoke increased responses (Novak et al., 2010). The property of EDA collected and analysed during our case study is the skin conductance, which is collected by measuring the electrical potential flow between two sensors placed on the skin. In simple terms, as features of arousal, such as stress, excitement or fear, a small amount of sweat is released into the skin (sweat glands). This sweat release changes the resistance of the skin to electrical current. The EDA sensor measures this change in resistance between the two sensors.

In terms of emotional processing, researchers have found it challenging to interpret the meaning of the variation of skin conductance. For example, the increase of arousal can be associated to negative feelings such as anxiety (Blechert, Lajtman, Michael, Margraf, & Wilhelm, 2006; Murakami & Ohira, 2007; Ritz, Thöns, Fahrenkrug, & Dahme, 2005), anger (Christie & Friedman, 2004; Dimberg & Thunberg, 2007; Ekman, 1984; Foster, Smith, & Webster, 1999; Tsai, Chentsova-Dutton, Freire-Bebeau, & Przymus, 2002), disgust (Demaree, Schmeichel, Robinson, & Evenhart, 2004; Ekman, 1984; Gruber, Johnson, Oveis, & Keltner, 2008), fear (Dimberg, 1986; Ekman, 1984; Levenson, Carstensen, Friesen, & Ekman, 1991) and sadness when this involves crying (Ritz, George, & Dahme, 2000; Tsai, Pole, Levenson, & Munoz, 2003; Vianna & Tranel, 2006). However, the increase of arousal can also indicate positive feelings such as amusement (Christie & Friedman, 2004; Demaree et al., 2004), happiness (Gehricke, 2002; Gruber et al., 2008; Hess, Kappas, McHugo, Lanzetta, & Kleck, 1992; Ritz et al., 2005), and joy (Vrana & Rollock, 2002). Increase in arousal can also indicate a mental workload (Novak et al., 2010). For this reason, combining the arousal measurements with other physiological signals, for example, thermography (see Section 5.3), can indicate if the response is positive or negative. When observing an increase of arousal, for example, a second indicator could indicate if the response is "excitement" or "stress".

An EDA complex signal includes both general tonic-level EDA (skin conductance level: SCL) and rapid phasic components (skin conductance responses: SCRs) that result from sympathetic neuronal activity, in other words, fight and flight responses. On the one hand, SCL responds to slower-acting components and background characteristics of the signal over time; it reflects changes in arousal. On the other hand, SCR responds to peaks and faster and automatic reactions which appear in the EDA signal. Each component relies on different neural mechanisms. They are different responses to different types of stress (Dawson, 2001; Nagai, Critchley, Featherstone, Trimble, & Dolan, 2004). Even though both are important, many researchers decide to rely on one or the other depending on the kind of responses they are looking at from their participants. In this case, both signals were studied and taken into consideration. Considering that the participants suffered from a sensory processing disorder, it was interesting to investigate whether the colour and source of the light could also affect the different types of stress and reactions differently.

In this research, the EDA signal was collected using skin conductance, which was recorded using Shimmer3 GSR+ Units. The palms of the hand and the arch of the foot are traditionally considered the more recommendable places to measure the data due to the high quantity of sweat glands located in these areas (Dooren, 2011). Considering that the participants needed to use their hands during the experiment to perform their activities, it was more convenient to place the two sensors in the arch of the foot because it was less disturbing to the participants. This location also enabled the device to gather the information with almost no noise due to the static position of the participants during the sessions since they were seated.

Before the EDA signals could be analysed, several preprocessing steps were applied (Chapter Four).

The variation of skin conductance is a relative measure, and the values can be different for different individuals. The main goal in this case study is to look at variations of skin conductance, and other signals which will be explained in Sections 5.3 and 5.4, and see if there is consistency in the results regarding the colour and source of the light within each participant. Considering that every participant is affected by sensory processing disorders differently, there is the assumption that every participant might react and behave differently to the different colours and sources of the light proposed for the test, and that every kind of light could evoke different feelings and emotions to every participant.

To compute the features, each of the EDA signals was decomposed into its slow-changing tonic and faster-changing phasic components. In particular, Benedek and Kaernbach 's deconvolution approach was the approach used (Benedek & Kaernbach, 2010) (see Chapter

Four, Section 4.3.1. for further explanation). Finally, the tonic EDA and the average number of phasic EDA peaks for each of the colour segments were extracted.

Physiological measures like EDA were analysed to see whether the colour or the source of the light influences the level of arousal of the participants. Two types of analysis were done. First, a daily analysis to see if a difference in the arousal exists within the same session regarding the colour of the light. Many variables can influence the data and having daily analysis reduces the number of variables massively. Variables that can influence the data can be the sleep quality of the previous night, food eaten during the day, different medication, unexpected events that occur on the day, among several others. These variables can alter the tolerance and levels of arousal of a person. Therefore, comparing the levels of arousal obtained on different days can sometimes provide misleading information because the variables could be different every day (and challenging control). As these variables are difficult to control, analysing the levels of arousal obtained under different light conditions during one particular day is very informative because the variables that affect the arousal are the same during every light exposure. It could be expected that, if a specific light influences the arousal consistently, the participant will have a similar level of arousal every time (s)he is exposed to this light during the same day. This consistency could be observed with the daily analysis, although in this case study, the sample is too small to see enough repetitions to see the consistency. The graphs obtained by day and physiological signals can be found in Appendices F, G and H, as will be mentioned throughout the chapter, when convenient. Secondly, all the measurements collected during the experiment were gathered, and the mean was calculated. The aim was to see if the results from both analyses are consistent and to see if it would be possible to extrapolate the results.

Both analyses differentiate the tonic and phasic EDA signal and are specific for every participant individually.

5.2.1. Participant F:

Analysis per day:

Influence of the colour of the light in the arousal and consistency of the results

All the data about EDA for Participant F can be found in Appendix F and show the tonic and phasic EDA obtained in every single session of the experiment for every light exposure for Participant F. Results show that every light exposure evoked different levels of arousal (EDA) in the participant. This finding indicates that both the colour and source of the light could have an impact on the physiological arousal because the level of arousal increases or increases depending on the different light conditions and did not remain similar under different light conditions throughout the session. This phenomenon was observed in every session.

Even though the results on the influence of the light in arousal were consistent in most of the cases, some inconsistencies were found, as well. For example, the participant was exposed to Yellow and Red lights on days 8, 9 and 10. On days 8 and 9, she had higher tonic and phasic EDA under Red than under Yellow. However, on day 10, she had lower EDA under Red than under Yellow (Figure 5.1). This finding indicates that another factor, out of our knowledge, could have influenced the results on day 10.

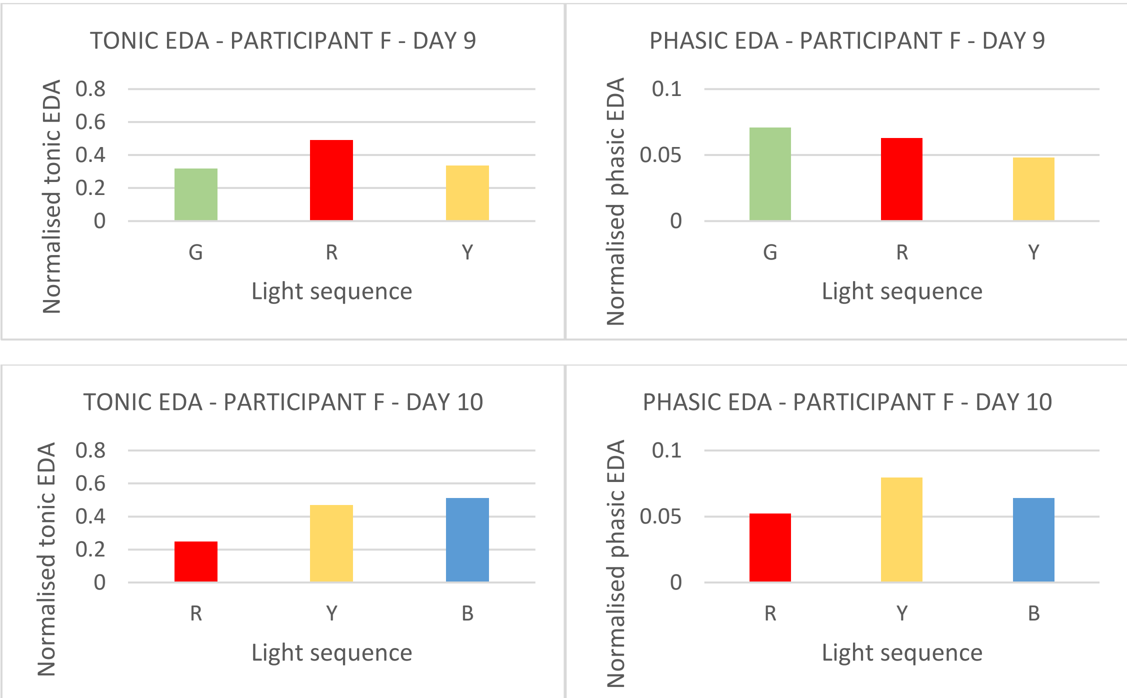

Figure 5. 1. Tonic EDA and Phasic EDA for Participant F obtained on days 9 and 10, under Red (R) and Yellow (Y), among other lights such as Green (G) and Blue (B).

Nevertheless, results show that the influence of the light in the arousal is consistent most of the times.

For example, comparing the arousal levels in Green and Blue lights, results show that the tonic response is higher under Green compared to Blue light on days 2, 7 and 14 (See Figure 5.2), although the results of Phasic EDA are not consistent on day 2. On day 7, although the lights were set in a different order, results show that the tonic arousal observed under Blue is also lower than tonic arousal under Green, consistently with results of tonic arousal of days 2 and 14. Therefore, the order did not seem to affect the impact of these lights on the arousal.

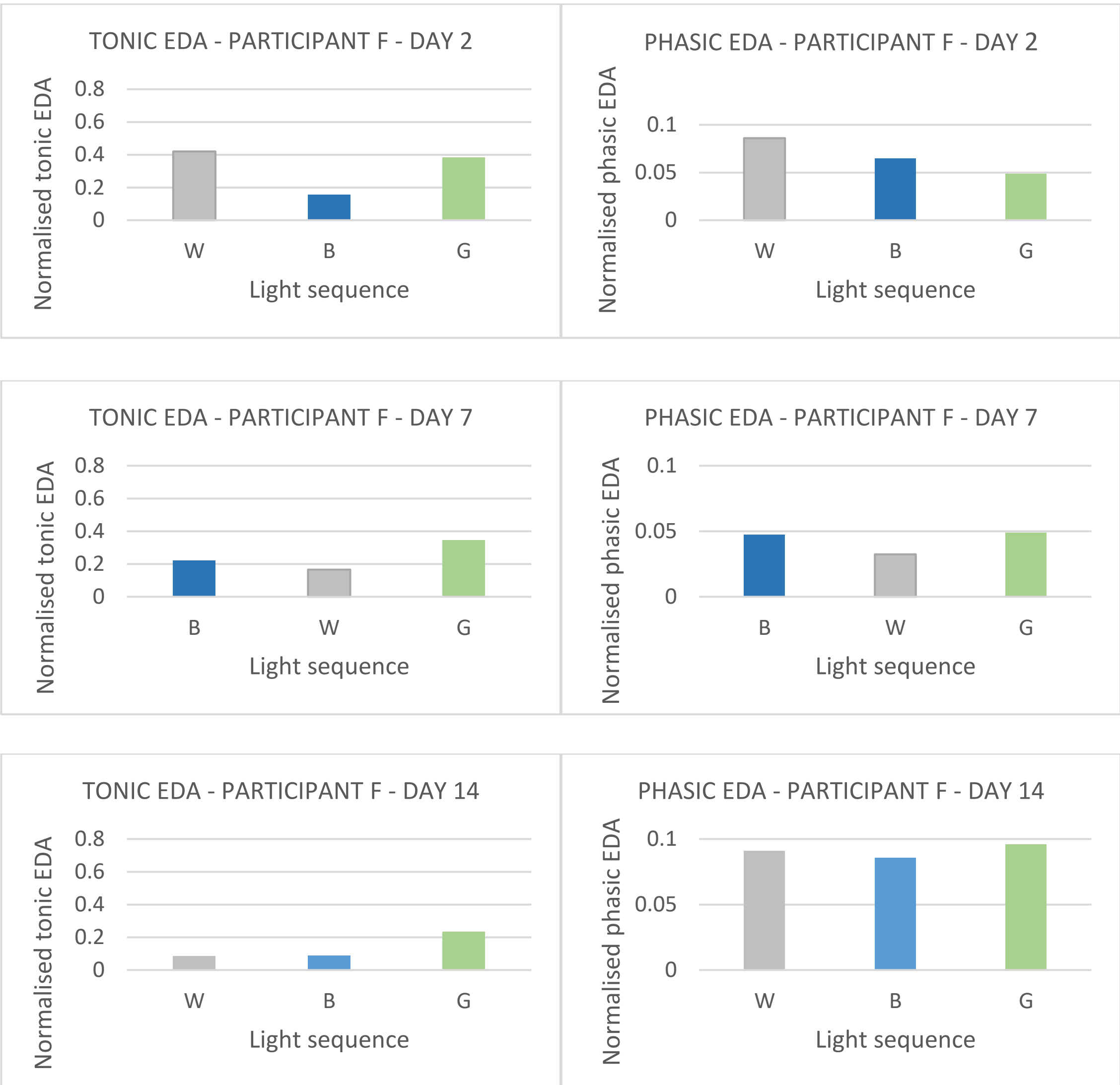

Figure 5. 2. Tonic EDA and Phasic EDA for Participant F obtained on days 2 and 14, under White (W), Blue (B) and Green (G).

When comparing Fluorescent light and Red LED exposures on days 4, 5 and 8 (Figure 5.3), results are consistent on days 4 and 5, showing a drop in the tonic and phasic response obtained from Fluorescent light compared to that for the Red Light. On day 8, although results of phasic EDA in both lights were similar, results of tonic EDA were slightly higher under Red light.

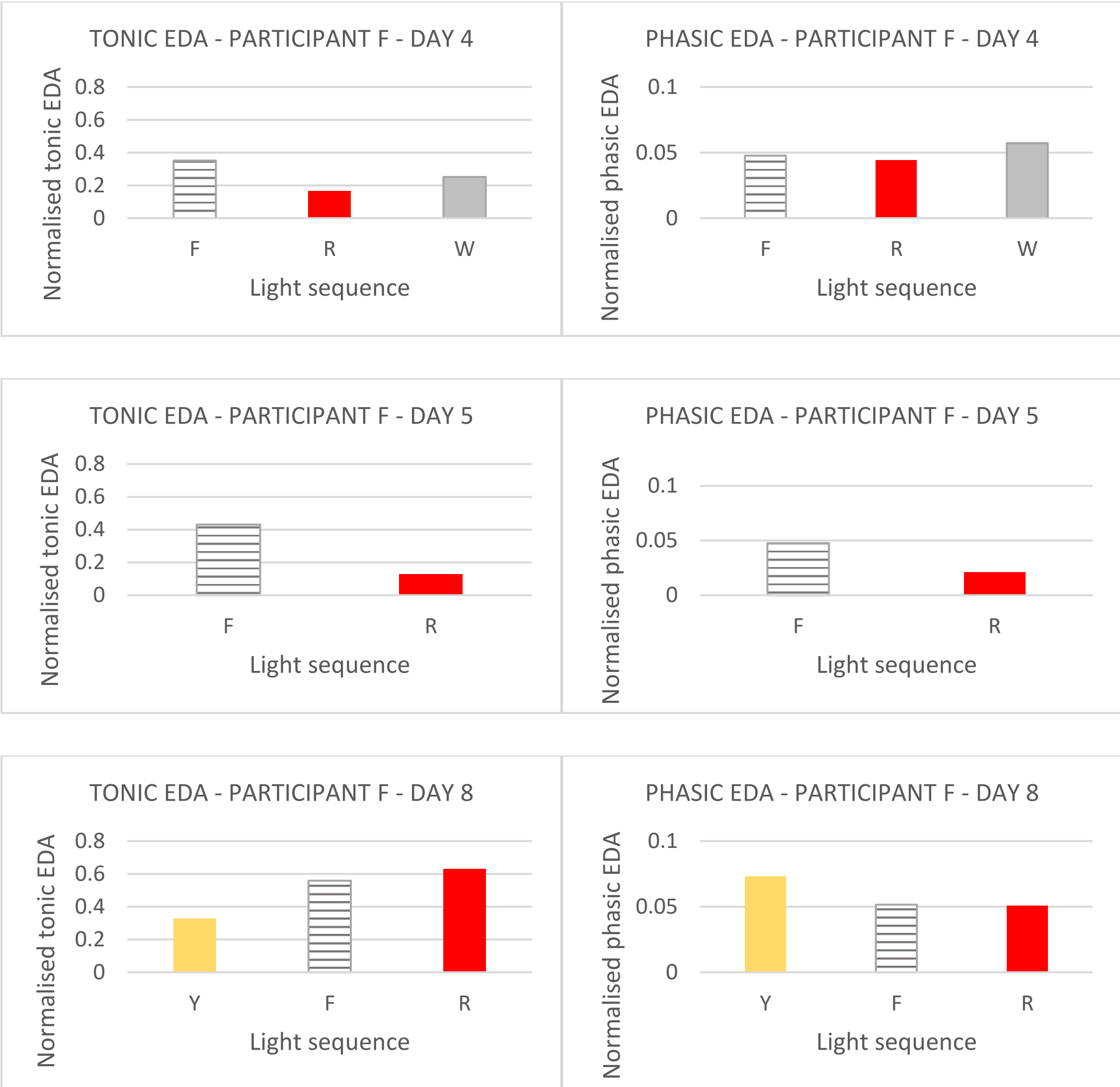

Figure 5. 3. Tonic EDA and Phasic EDA for Participant F obtained on days 4, 5 and 8, under Fluorescent light (F), Red (R) Yellow (Y) and White (W).

Patterns observed across the days

In some cases, such as days 7, 8, 9, 11, 12, 13 and 14, the tonic arousal had an upward trend-line with different sequences of light, as shown in the example displayed on Figure 5.4. These results could call into question the idea that there is a consistent influence of the colour of the light on the arousal. As will be discussed in Chapter Eight, this fact can respond to different reasons: whether the colour or the source of last light of the light sequence of the session is which induces the increase in arousal, or the levels of excitation, stress or concentration (the body responds to these three emotions/behaviours by increasing the level of arousal) might increase during the session. If it was the second case, the EDA results obtained might be influenced by the activity more than the light conditions. In order to clarify this, the EDA signals should be first compared with other physiological signals such as the temperature of the tip of the nose (Section 5.3) and see if the same pattern is observed, and secondly, further responses should be recorded under different light sequences to compare the results and see if the results are consistent with the light conditions or with the activity.

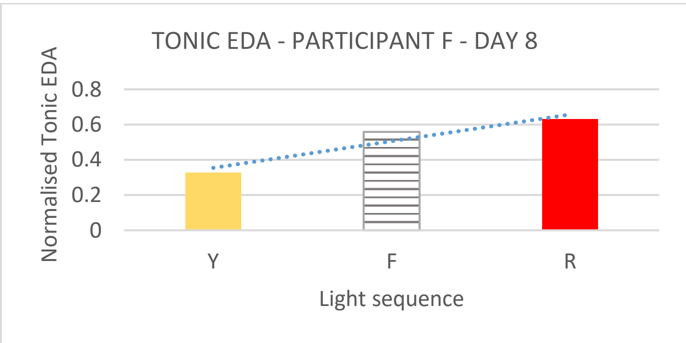

Figure 5. 4. Upward trend-line of Tonic EDA for Participant F under Yellow (Y), Fluorescent light (F) and Red (R), obtained on day 8.

Influence of the source of the light in the arousal: Fluorescent light vs White LED

The influence of the source of the light in the arousal of the participant was checked comparing Fluorescent light and White light. Both lights were set in the same session on days 4, 11 and 12 (Figure 5.5) although they were set in a different order. On days 4 and 11, the tonic response was higher under Fluorescent light. On day 12, even though the tonic responses under both lighting conditions were similar, the phasic response was also higher under Fluorescent light, showing higher arousal under Fluorescent light compared to White in all the results. Therefore, results indicate that Fluorescent light might be more arousing than White.

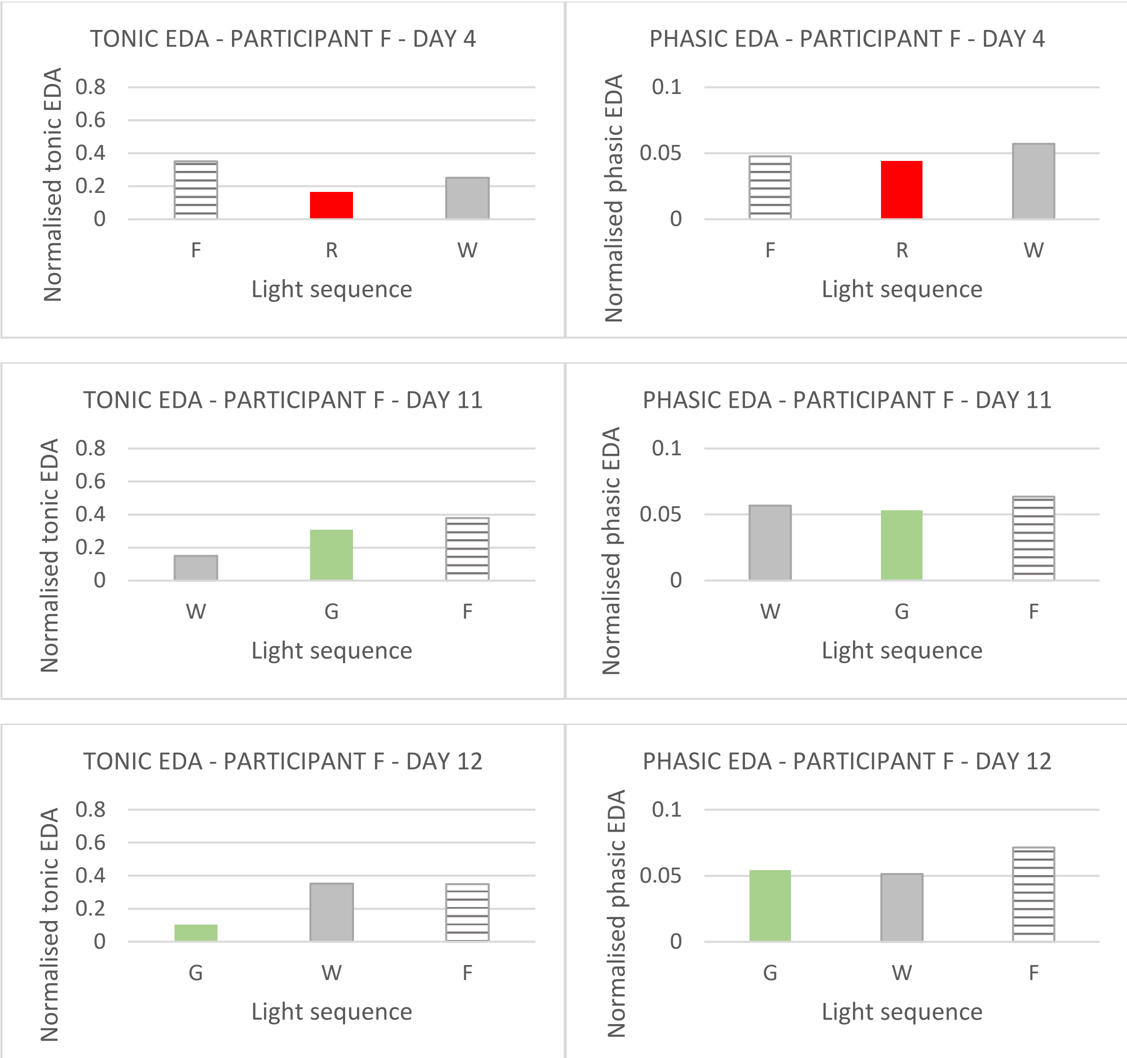

Figure 5. 5. Tonic EDA and Phasic EDA for Participant F obtained on days 4, 11 and 12. Participant F experienced White (W) and Fluorescent light (F).

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Summary all days:

Figure 5.6 shows the mean level of physiological arousal for each of the light exposures collected during the case study for Participant F. Results show different levels of arousal depending on the colour of the light. This finding indicates that the colour of the light could have an impact on the arousal of the participant, as observed in the daily analysis.

The results indicate that Participant F had higher levels of tonic arousal (long-term situations) and was more activated under Yellow (Mean=0.44, Range 0.33-0.61) conditions, followed by Fluorescent light (Mean=0.39, Range 0.25-0.56). Regarding phasic arousal, in other words, the number of peaks or reactions to sudden stimuli, the participant was more reactive under White (Mean=0.067, Range 0.03-0.09), Yellow (Mean=0.063, Range 0.05-0.08), Green (Mean=0.065, Range 0.05-0.10) and Blue (Mean=0.068, Range 0.04-0.09) light conditions.

Participant F had lower levels of tonic arousal under Blue (Mean=0.20, Range 0.09-0.5) in which the skin conductivity descended more than 50% of the arousal under Yellow. That is, in long-term situations, Participant F was low aroused and calmer under Blue than under any other lights as if Blue could induce a calming effect. Regarding phasic arousal, the participant reacted less to the stimuli under Fluorescent light (Mean=0.055, Range 0.05-0.07) and Red (Mean=0.051, Range 0.02-0.08) light conditions compared to any other light. That is that Participant F was less reactive to the stimuli from the environment under Fluorescent and Red conditions.

Results shown in Figure 5.6 show that Fluorescent light might be more arousing in long-term situations than White as the mean Tonic EDA is higher under Fluorescent than under White. This finding indicates that Participant F is more activated/aroused under Fluorescent. However, Participant F seemed to be more reactive to sudden stimuli under White LED as results on the mean Phasic EDA indicate. This finding indicates that the source of the light could have an impact on the physiological level, in this case, on the arousal and the activation of the participant.

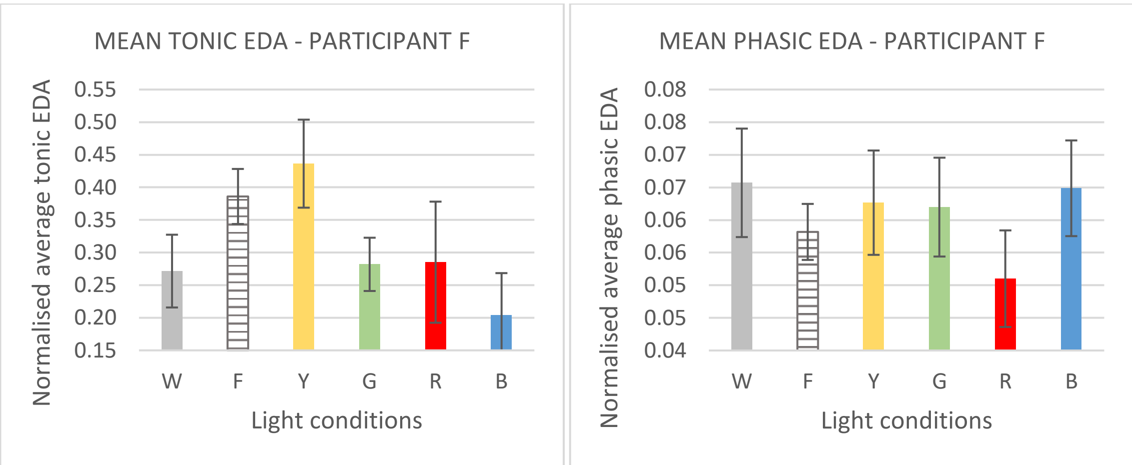


Figure 5. 6. Tonic EDA and Phasic EDA for Participant F under every light used, obtained during the case study.

5.2.2. Participant FX:

Analysis per day:

Influence of the colour of the light in the arousal and consistency of the results

All the data about EDA for Participant FX can be found in Appendix F and show the tonic and phasic EDA obtained from every single session of the experiment for every light exposure for Participant FX. Results show that every light exposure evoked different levels of arousal in the participant. This finding indicates that both the colour and source of the light could have an impact on the physiological arousal because the level of arousal increases or increases depending on the different light conditions and did not remain similar under different light conditions throughout the session. This phenomenon was observed in every session.

Even though the results on the influence of the light in arousal were consistent in most of the cases, some inconsistencies were found, as well. For example, the participant was exposed to Yellow and Red lights on days 5, 8, 9 and 10. On days 5, 8 and 9, he had higher EDA under Red than under Yellow. However, on day 10, he had lower EDA under Red than under Yellow (Figure 5.7). This finding indicates that another factor, out of our knowledge, could have influenced the results on day 10. This factor might be shared in the school environment because the same results were observed in Participant F.

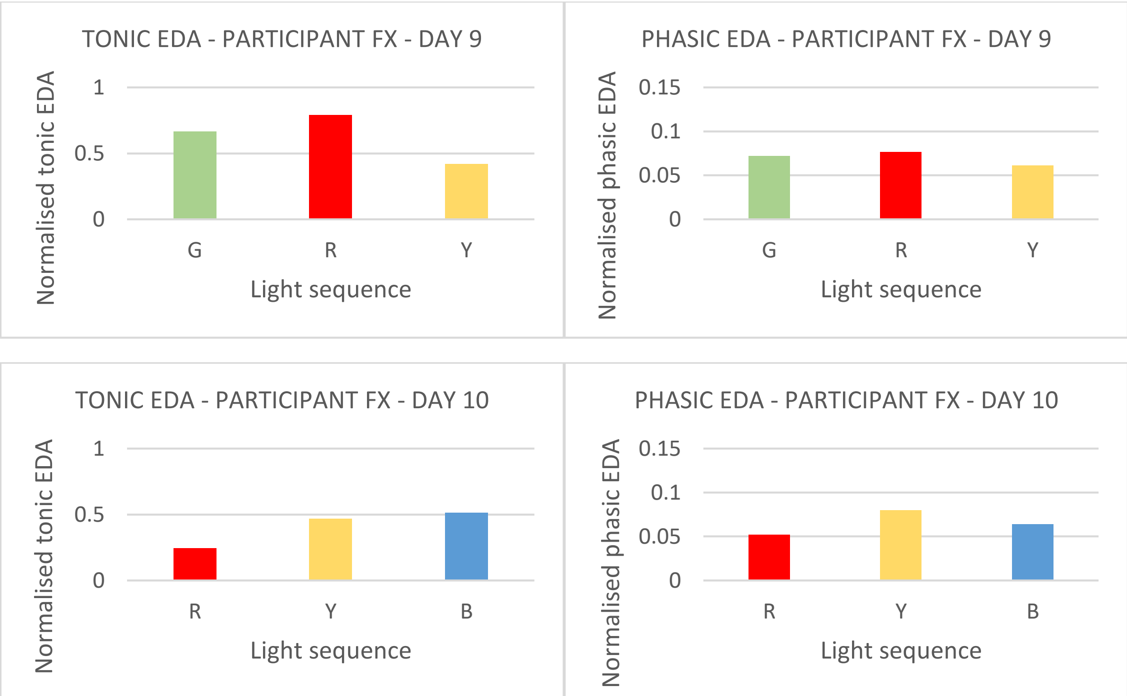


Figure 5. 7. Tonic EDA and Phasic EDA for Participant FX obtained on days 9 and 10, under Red (R) and Yellow (Y), among other lights such as Green (G) and Blue (B).

On the contrary, this was not the case for White and Blue. Observing White and Blue lights which were exposed in the same sessions four times – on days 2, 7, 13 and 14 (Figure 5.10), when the light transitioned from White to Blue the tonic arousal tended to increase but the arousal also increased when the light transitioned from Blue to White. In this case, the light can affect the arousal, but the results are not always consistent.

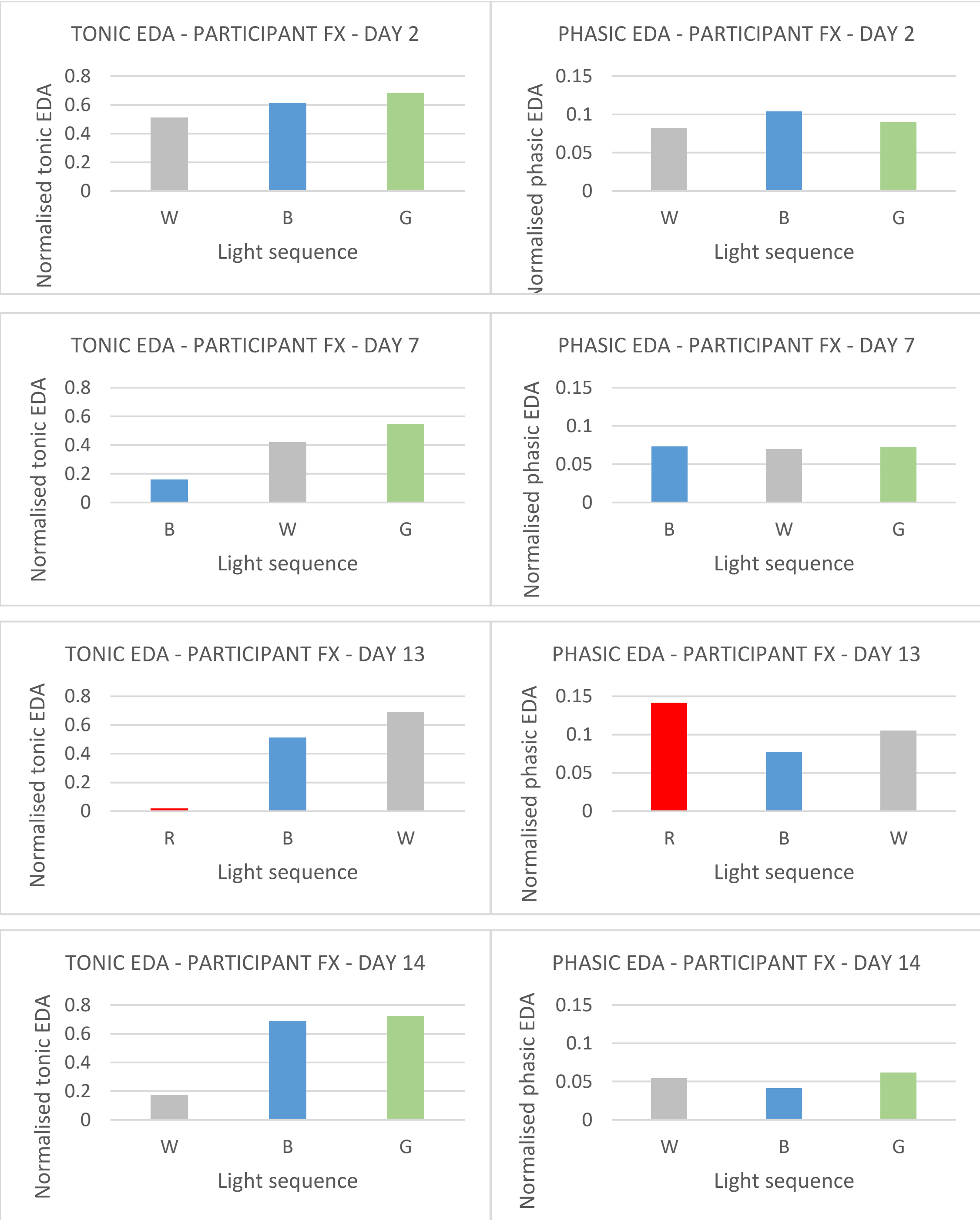


Figure 5. 8. Tonic EDA and Phasic EDA for Participant FX under White (W) and Blue (B), among other lights such as Green (G) and Red (R), obtained on days 2, 7, 13 and 14.

However, many cases were consistent. For example, comparing arousal levels under Green and Blue lights, results show that the tonic response is lower under Blue compared to Green on days 2, 6, 7 and 14 (Figure 5.8). On day 7, both lights were set in a different order. Tonic arousal observed under Blue is also lower than tonic arousal under Green, being consistent with other days. These results indicate that the order of the light sequence might not be essential in the influence of the arousal. These consistencies, though, were not found in results of phasic EDA.

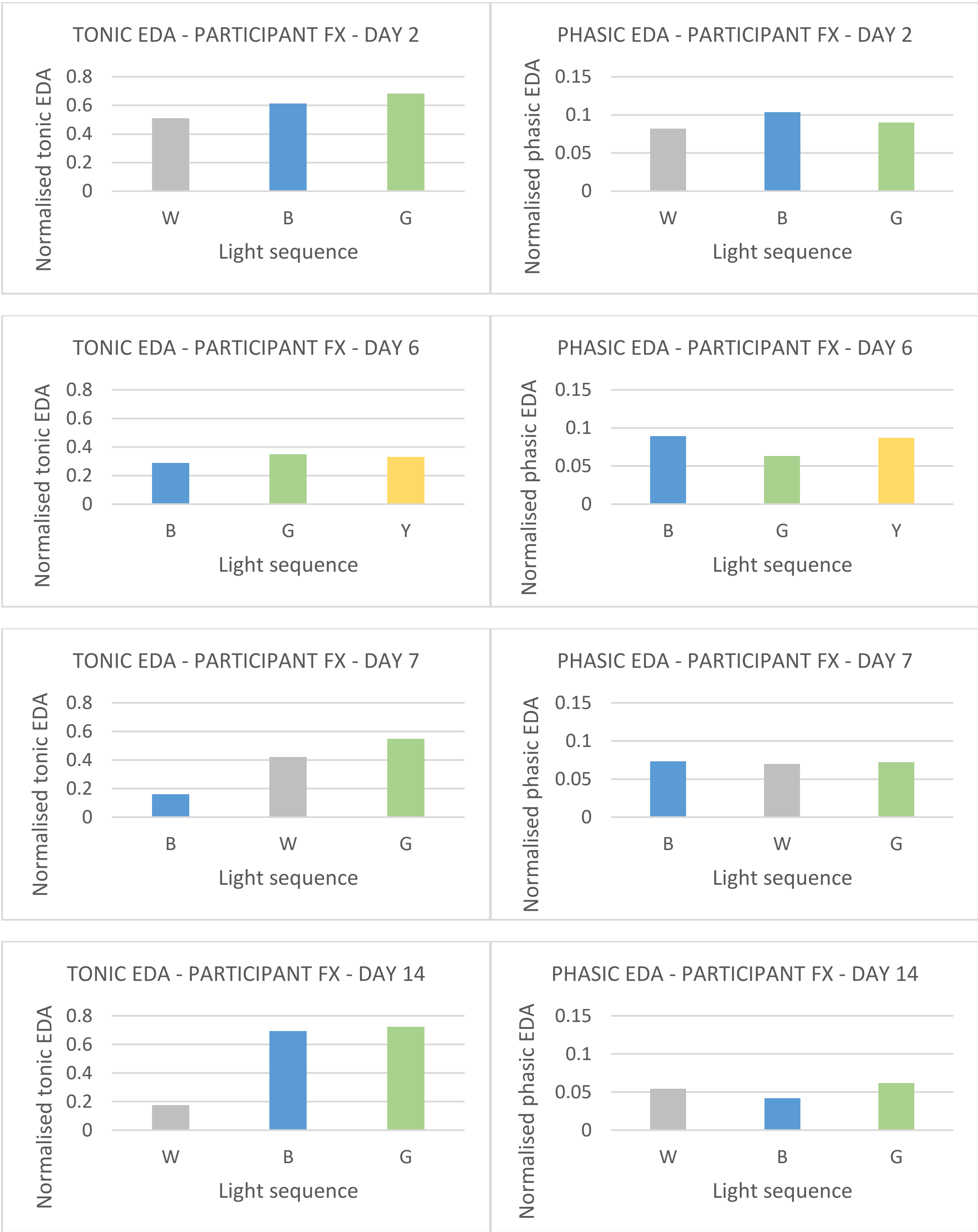


Figure 5. 9. Tonic EDA and Phasic EDA for Participant FX under Blue (B) and Green (G), among others lights such as White (W), Yellow (Y), obtained on days 2, 6, 7 and 14.

Another example is the difference between Fluorescent light and Red on days 4, 5 and 8 (Figure 5.9). Tonic arousal obtained during Fluorescent light is always lower than the arousal obtained during Red. However, again, this consistency was not found on the phasic EDA.

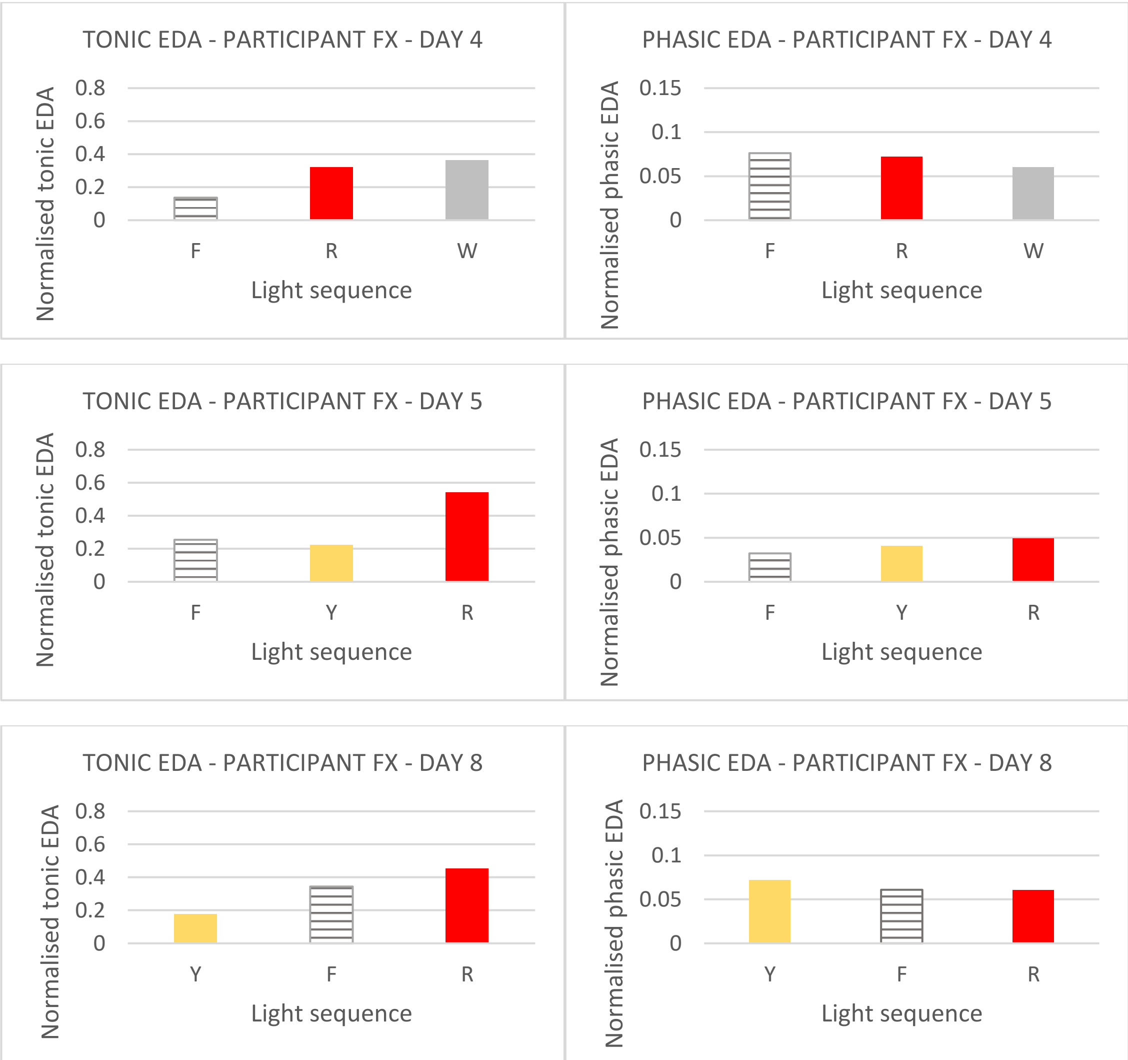


Figure 5. 10. Tonic EDA and Phasic EDA for Participant FX under Fluorescent light (F) and Red (R), among other lights such as Yellow (Y) and White (W), obtained on days 4, 5 and 8.

Patterns observed across the days

In some cases, such as days 4, 7, 8, 10, 13 and 14, the tonic arousal had an upward trend-line with different sequences of light as can be seen in Figure 5.11. These results could call into question the idea that there is a consistent influence of the colour of the light on the arousal.

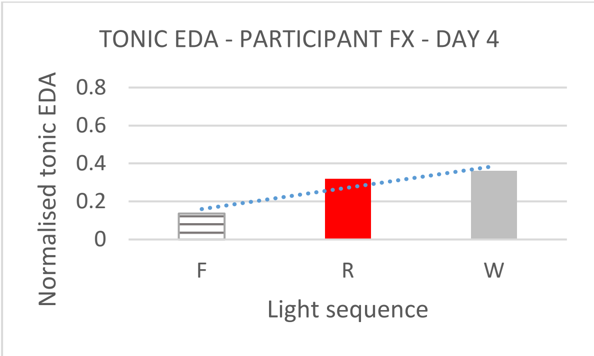


Figure 5. 11. Upward trend-line of Tonic EDA for Participant FX under Fluorescent light (F), Red (R) and White (W), obtained on day 4.

As will be discussed in Chapter Eight and was already mentioned in Section 5.2.1, this fact can respond to different reasons: whether the colour or the source of last light of the light sequence of the session is which induces the increase in arousal, or the levels of excitation, stress or concentration (the body responds to these three emotions/behaviours by increasing the level of arousal) might increase during the session. If it was the second case, the EDA results obtained might be influenced by the activity more than the light conditions. In order to clarify this, the EDA signals should be first compared with other physiological signals such as the temperature of the tip of the nose (Section 5.3) and see if the same pattern is observed, and secondly, further responses should be recorded under different light sequences to compare the results and see if the results are consistent with the light conditions or with the activity.

Influence of the source of the light in the arousal: Fluorescent light vs White LED

Regarding the influence of the source of the light in the arousal of the participant, both lights were set in the same session on days 4 and 12 (Figure 5.12), although they were set in a different order. The tonic response was lower under Fluorescent light in both cases. Therefore, White seems to be more arousing than Fluorescent light. Results show same levels of phasic arousal between both lights.

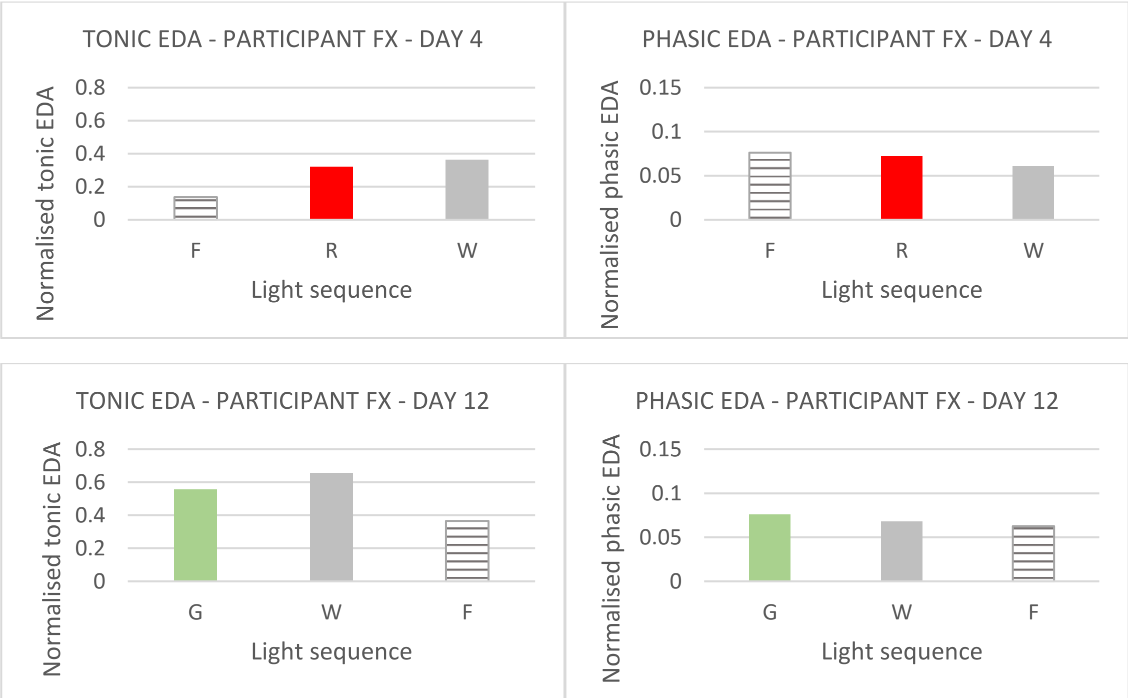


Figure 5. 12. Tonic EDA and Phasic EDA for Participant FX under White (W) and Fluorescent light (F), among other lights such as Red (R) and Green (G), obtained on days 4 and 12.

Summary all days:

Figure 5.13 shows the mean level of physiological arousal for each of the light exposures collected during the two-month experiment from Participant FX. Results on arousal are different depending on the colour of the light. This finding indicates that the colour of the light could have an impact on the arousal of the participant, as seen in the daily analisis.

Results indicate that Participant FX had higher levels of tonic arousal under Green (Mean=0.57, Range 0.35-0.7) conditions, followed by a Blue (Mean=0.48, Range 0.16-0.69). Regarding phasic arousal, the participant experienced higher and similar number of peaks under White

(Mean=0.075, Range 0.05-0.11), Blue (Mean=0.075, Range 0.04-0.10), Red (Mean=0.077, Range 0.05-0.14) and Green (Mean=0.072, Range 0.06-0.09).

Participant FX had lower levels of tonic arousal under Yellow (Mean=0.35, Range 0.18-0.66) followed by Fluorescent light (Mean=0.37, Range 0.14-0.73). Regarding phasic arousal, the participant reacted less to external stimuli under Fluorescent light (Mean=0.064, Range 0.03-0.08), and Yellow (Mean=0.061, Range 0.04-0.87) conditions than under any other light.

Results shown in Figure 5.13 also show that Fluorescent light might be less arousing in both long-term situations and rapid stimuli than White. This finding indicates that the source of the light could have an impact on the physiological level.

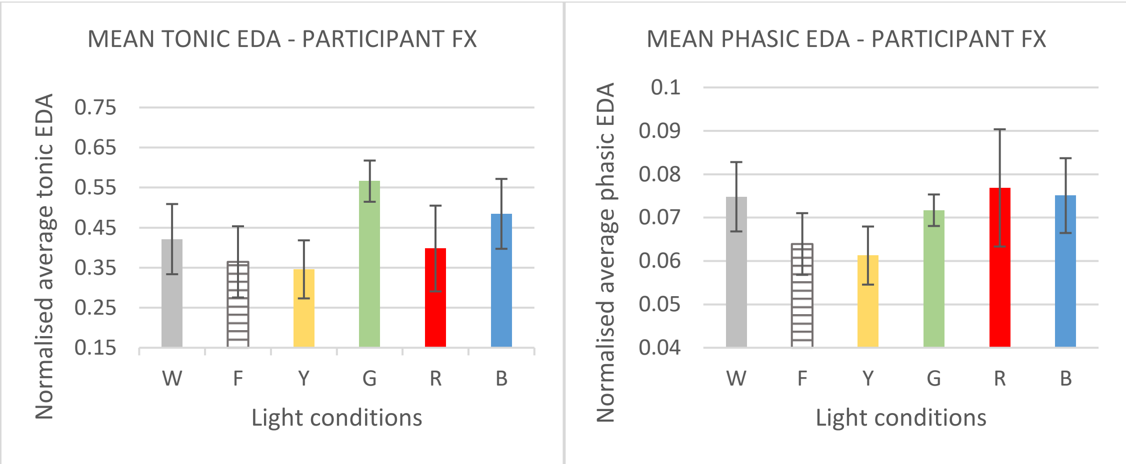


Figure 5. 13. Average Tonic EDA and Phasic EDA for Participant FX under every light used, obtained during the case study.

5.2.3. Participant H:

Analysis per day:

Influence of the colour of the light in the arousal and consistency of the results

All the data about EDA for Participant H can be found in Appendix F and show the tonic, and phasic EDA obtained every single session of the experiment for every light exposure for Participant H. Results show that every light exposure evoked different levels of arousal in the participant. This finding indicates that both the colour and source of the light could have an impact on the physiological arousal because the level of arousal increases or increases depending on the different light conditions and did not remain similar under different light conditions throughout the session. This phenomenon was observed in every session.

For example, comparing arousal levels in White and Blue lights, results show that both the tonic and phasic response is higher under Blue compared to White on days 7 and 14 (Figure 5.14). That result indicates that the results seemed consistent.

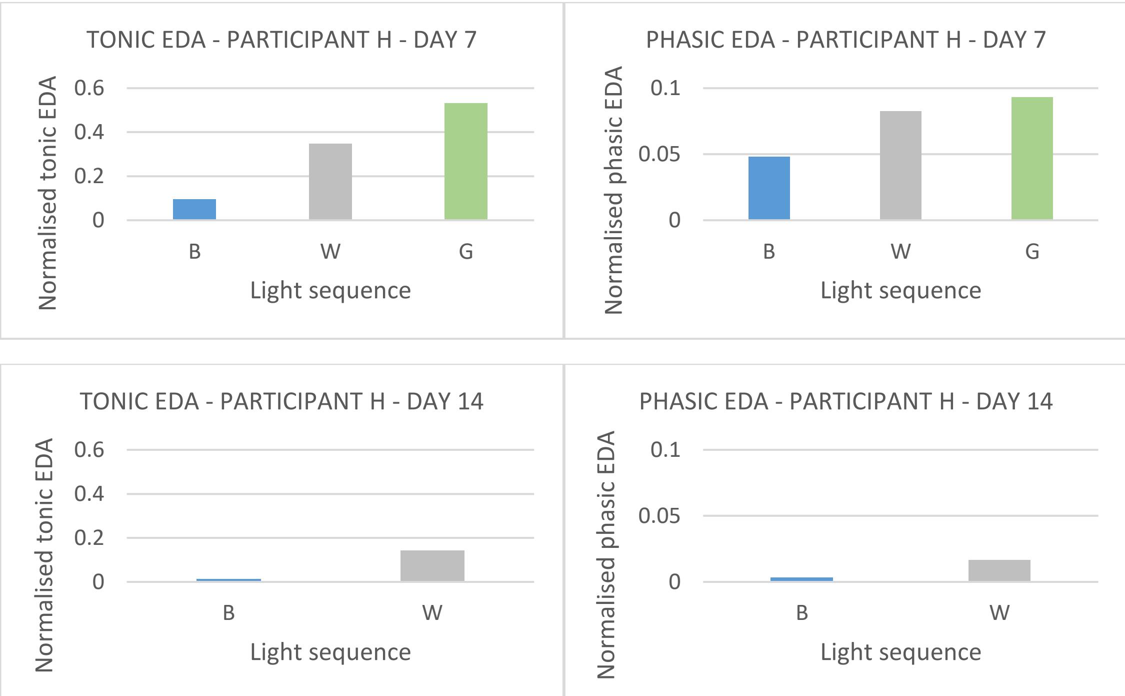


Figure 5. 14. Tonic EDA and Phasic EDA for Participant H under Blue (B) and White (W), among other lights such as Green (G), obtained on days 7 and 14.

Patterns observed across the days

The fluctuations do not respond to a particular pattern. This finding indicates that Participant H could be influenced by the light conditions, and the pattern of the arousal responds to its influence.

Influence of the source of the light in the arousal: Fluorescent light vs White LED

The influence of the source of light in the arousal of the participant was mean to be checked to compare White LED and Fluorescent light, but data is insufficient even to have a guess. Both lights were set in the same session only on day 4 (Figure 5.15). Both signals, the tonic response and the phasic response, were higher under Fluorescent light than under White light.

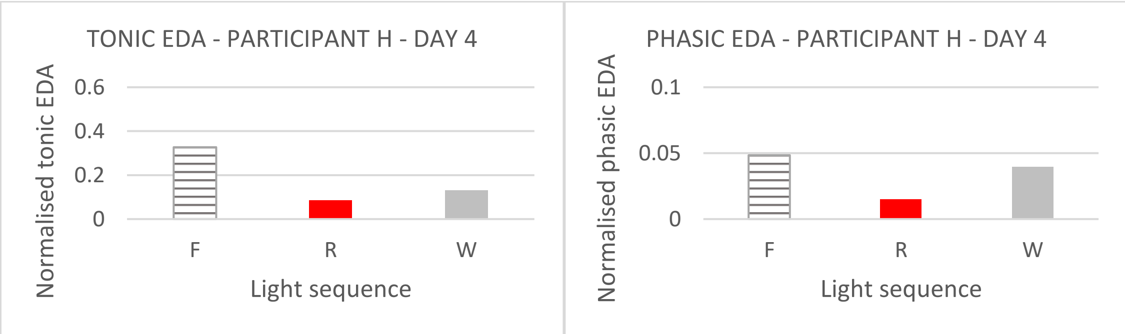


Figure 5. 15. Tonic EDA and Phasic EDA for Participant H under Fluorescent light (F), Red (R) and White (W), obtained on day 4.

Summary all days:

Figures 5.16 show the mean level of physiological arousal for each of the light exposures collected along with the two-month experiment for Participant H; however, the data collection was particularly limited. Results on arousal are different depending on the colour of the light. This finding would indicate that the colour of the light could have an impact on the arousal of the participant, as seen in the daily analisis.

Results indicate that Participant H had higher levels of tonic arousal under Fluorescent light (Mean=0.33, Range 0.33-0.33) conditions, followed by Green (Mean=0.31, Range 0.18-0.53). Regarding phasic arousal, the participant experienced higher and similar peaks under White

(Mean=0.046, Range 0.02-0.08) and Fluorescent light (Mean=0.048, Range 0.048-0.048) light conditions.

Participant H had lower levels of tonic arousal under Blue (Mean=0.05, Range 0.01-0.1). Regarding phasic arousal, the participant reacted less to external stimuli under Red (Mean=0.015, Range 0.01-0.02) light conditions than under any other light.

Results shown in Figure 5.16 also show that Fluorescent light would be more arousing in long-term situations than White light. However, Participant H was reactive to external and rapid stimuli from the environment similarly under White LED and Fluorescent light. This finding indicates that the source of the light could have an impact on the physiological level, but more samples would be necessary.

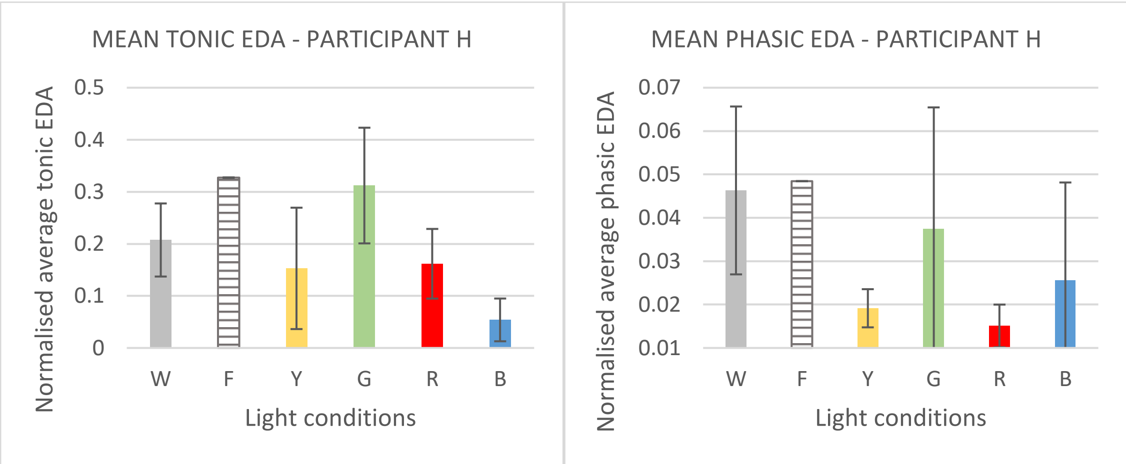


Figure 5. 16. Average Tonic EDA and Phasic EDA for Participant H under every light used, obtained during the case study.

5.2.4. Participant J:

The sessions of Participant J suffered alterations compared to the other participants because the participant wanted to change the colour of the light often. On the one hand, as Participant J sometimes asked for a change in the colour of the light, he experienced light exposures of less than 30 seconds which might not show alterations in the physiological signals such as EDA; therefore, these values might not be comparable to the ones obtained during longer exposures (Caldwell & Jones, 1984). Nevertheless, even though these exposures cannot be compared to the longer exposures, they do represent a characteristic of this participant in the sense that he was the only one who made such requests, so they were retained for the analysis and future discussion.

On the other hand, Participant J also asked for darker versions of the colour blue. The new tone was obtained by changing only the hue of the light, maintaining the saturation and the intensity so that they were the same as the rest of the light exposures. As seen in Chapter Two, different values of the properties of the colour, such as hue can influence the individual differently (Wilms & Oberfeld, 2016). Consequently, even though the exposures with new different hues will be considered as “Blue” for easier comprehension, the changes will be noted so any alterations in the results could be considered and discussed in the future.

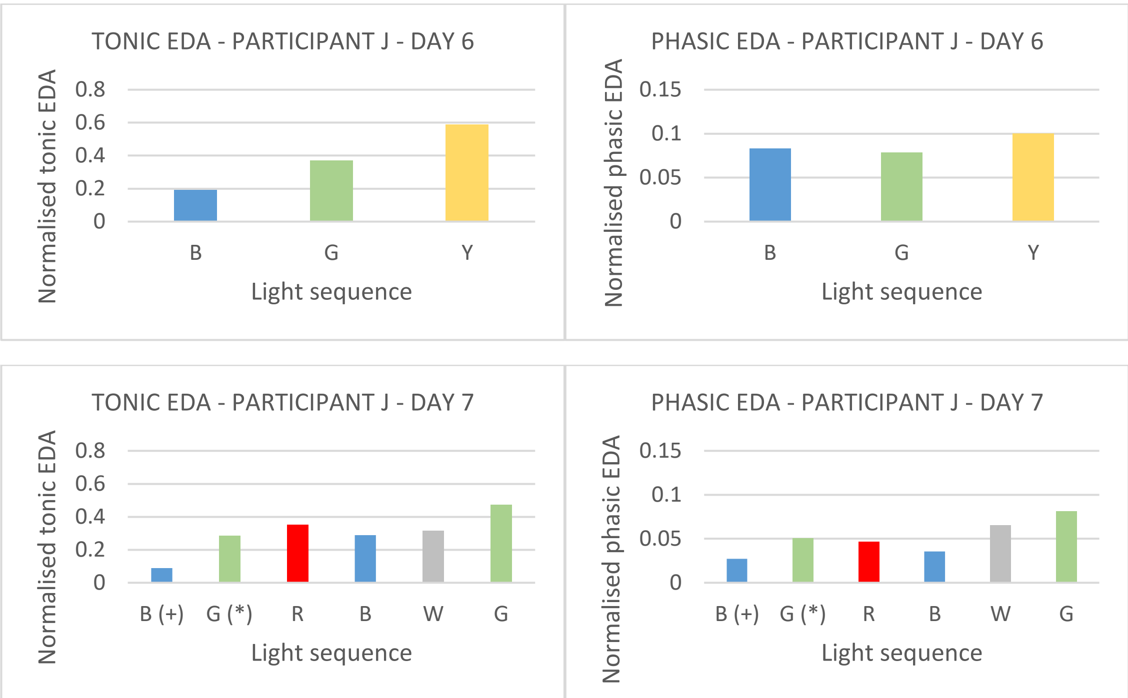
When the participant asked to change Blue to a darker tone of blue it will be symbolised in the Figures with the symbol (+). As the property of the hue was different, results might be less significant, comparatively speaking. When, due to his requests, the duration of the light exposures lasted less than 30 seconds, it will be symbolised with the symbol (*). As the duration was minimal, the results might be less significant, as well.

Analysis per day:

Influence of the colour of the light in the arousal and consistency of the results

All the data about EDA for Participant J can be found in Appendix F and show the tonic and phasic EDA obtained every single session of the experiment for every light exposure for Participant J. Results show that every light exposure evoked different levels of arousal in the participant. This finding indicates that both the colour and source of the light could have an impact on the physiological arousal because the level of arousal increases or increases depending on the different light conditions and did not remain similar under different light conditions throughout the session. This phenomenon was observed in every session.

For example, comparing arousal levels in Green and Blue lights from days 6, 7, 8, 10, 11 and 14 (Figure 5.17) results show that the tonic and phasic response is lower under Blue than under Green except from days 10 and 11. On day 11, however, the participant asked for a darker tone of blue. The difference in the hue might have influenced the results differently.



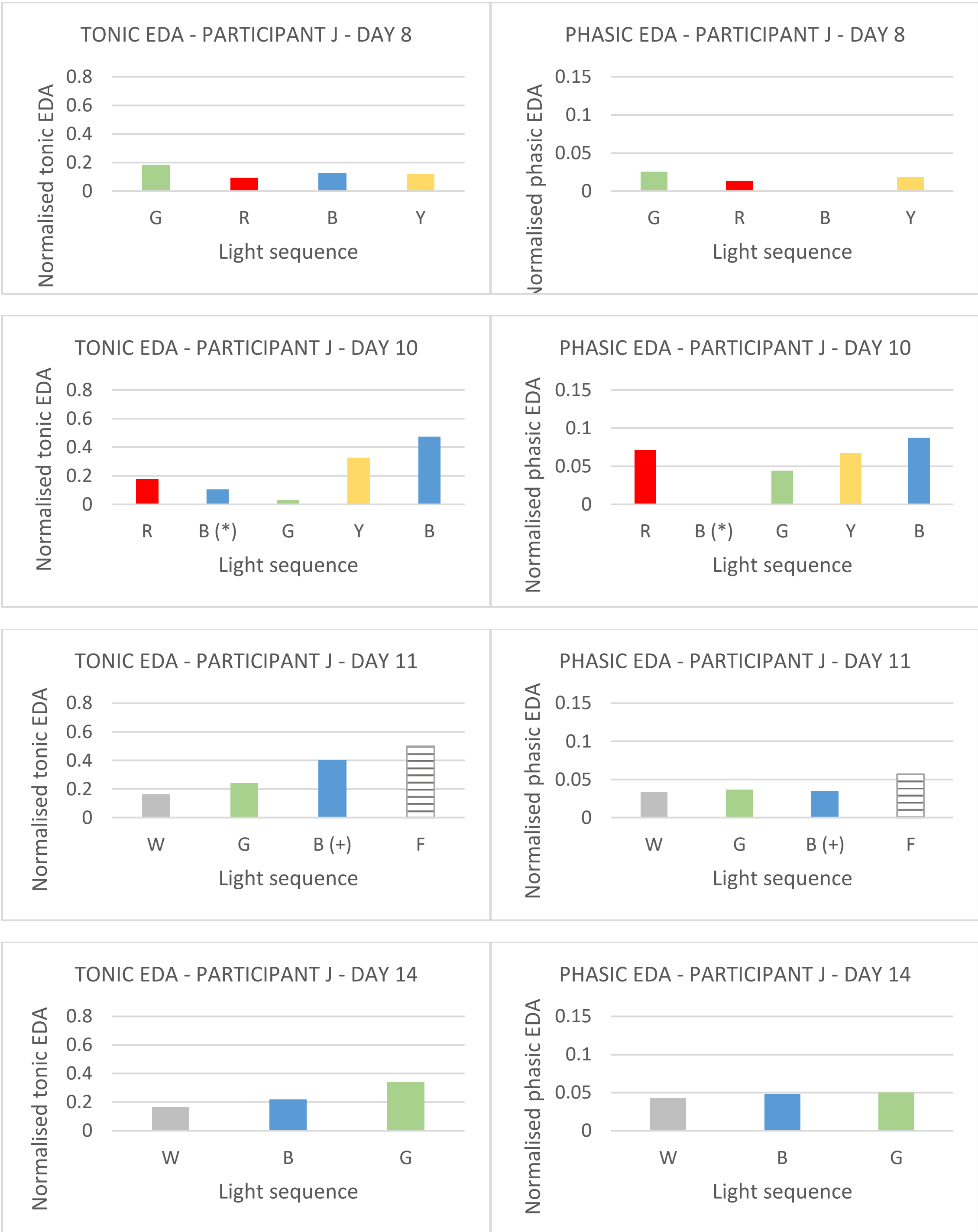


Figure 5. 17. Tonic EDA and Phasic EDA for Participant J under Blue (B) and Green (G) lights, among other lights such as Fluorescent (F) Yellow (Y), Red (R) and White (W), obtained on days 6, 7, 8 10, 11, and 14.

Patterns observed across the days

Results also show there is not a repeated pattern of arousal among the sessions. That could indicate that Participant J could be influenced by the colour of the light, and the trend-line of the arousal depends on the colour ar source of the light.

Influence of the source of the light in the arousal: Fluorescent light vs White LED

Regarding the influence of the source of the light in the arousal of the participant, comparing Fluorescent light and White LED. Both lights were set in the same session on days 4, 9 and 11 (Figure 5.18) although they were set in a different order. Figure 5.18 shows that on days 4 and 9, the tonic arousal was higher under White compared to Fluorescent light. Figure 5.18 also shows that on day 11, however, the arousal was higher under Fluorescent light than under White light. Therefore, results of tonic arousal were not consistent, and it was not possible to determine which of the two sources is more arousing in long-term situations. However, the phasic arousal was always higher under Fluorescent light.

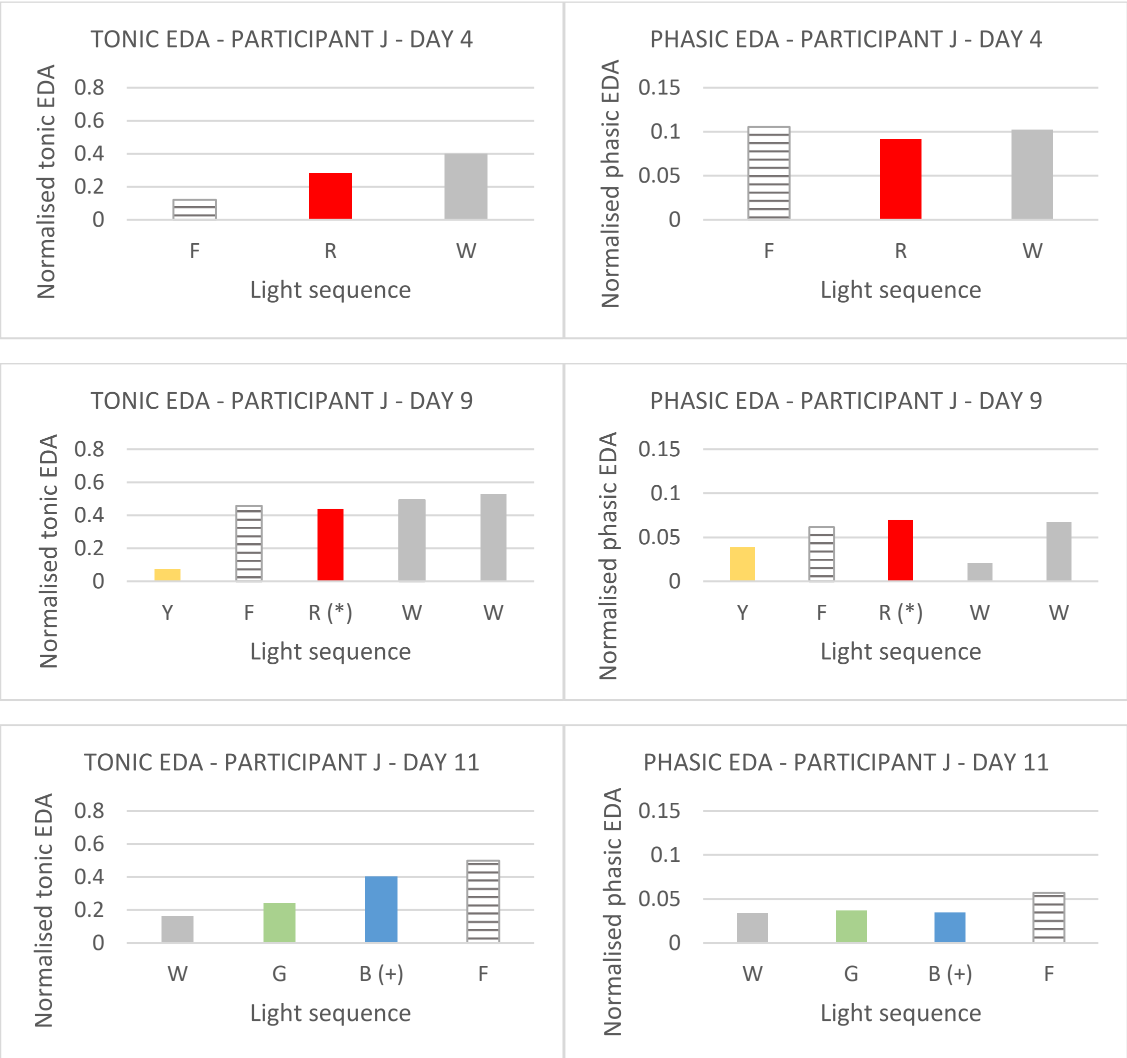


Figure 5. 18. Tonic EDA and Phasic EDA for Participant J under White (W) and Fluorescent light (F), among other lights such as Red (R), Yellow (Y), Blue (B) and Green (G) obtained on days 4, 9 and 11.

Summary all days:

Figure 5.19 shows the mean level of physiological arousal for each of the light exposures collected along with the two-month experiment for Participant J. Results on arousal is different depending on the colour of the light. This finding indicates that the colour of the light could have an impact on the arousal of the participant, although the tonic arousal on Green, Red and Blue are similar.

Results indicate that Participant J had higher levels of both tonic and phasic arousals under Fluorescent light (Mean=0.36, Range 0.12-0.5, Mean=0.063, Range 0.05-0.11, respectively) conditions than under any other light.

Participant J had lower levels of both tonic and phasic arousals under Blue (Mean=0.27, Range 0.05-0.61, Mean=0.037 Range 0-0.09, respectively) than under any other light. This finding indicates that Participant J might feel more relaxed and pleased under Blue conditions. This fact could be the reason why he asked several times to change the colour of the light to Blue light.

Results on 5.19 show that Fluorescent light might be more arousing in long and short-term situations than White light. This finding could indicate that the source of the light could have an impact on the physiological level.

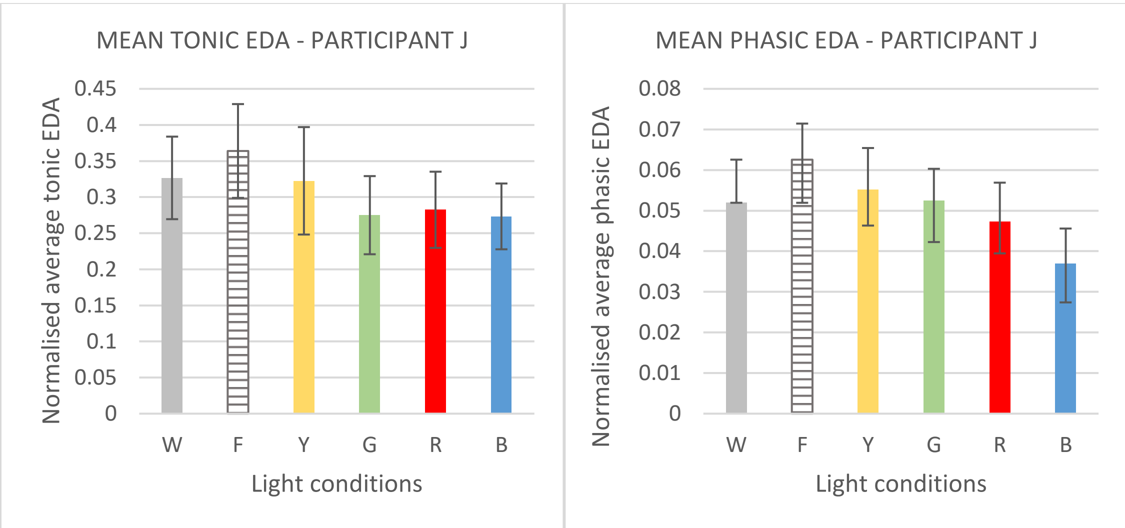


Figure 5. 19. Average Tonic EDA and Phasic EDA for Participant J under every light used, obtained during the case study.

As mentioned before, participant J wanted to change the colour of the light often and even the tone of the light. This attitude resulted in variations of time and hue. As previously seen in the literature, both factors can have a significant influence on the results. For this reason, Figure 5.20 shows the mean level of physiological arousal for the light exposures collected along with the two-month experiment for Participant J, avoiding all the exposures shorter than 30 seconds and the exposures which altered the properties of the light.

The only lights affected by these two variations were the lights Green, Red, and Blue. Results on arousal are different depending on the colour of the light. This finding indicates that the colour of the light could have an impact on the arousal of the participant, although the tonic arousal on Green, Red and Blue are similar.

Similarly to the other calculations, results indicate that Participant J had higher levels of both tonic and phasic arousals under Fluorescent light (Mean=0.36, Range 0.12-0.5, Mean=0.063, Range 0.05-0.11, respectively) conditions than under any other light.

Nevertheless, when omitting the light exposures which lasted less than 30 seconds and the light exposures which altered the hue of the light, results show that Participant J had lower levels of both tonic, and phasic arousals under Red (Mean=0.26, Range 0.09-0.55, Mean=0.045 Range 0-0.09, respectively) followed closely by Blue (Mean=0.27, Range 0.05-0.5, Mean=0.047 Range 0-0.09, respectively). This finding indicates that Participant J might feel less aroused under Red conditions instead of Blue as the other calculations showed. The comparison with other physiological signals is crucial here, low arousal could indicate relaxation but as the participant was reductant to experience Red (showing aggressive behaviour under Red and asking to change the colour of the light when this light was set) the low arousal might indicate sadness, annoyance or tiredness. Instead, he asked several times to change the colour of the light to Blue, which present similar level of arousal but the low arousal, in this case, was taken as a sign that he seemed to enjoy the light.

Results on 5.20 show that Fluorescent light might be more arousing in long and short-term situations than White. This finding could indicate that the source of the light could have an impact on the physiological level.

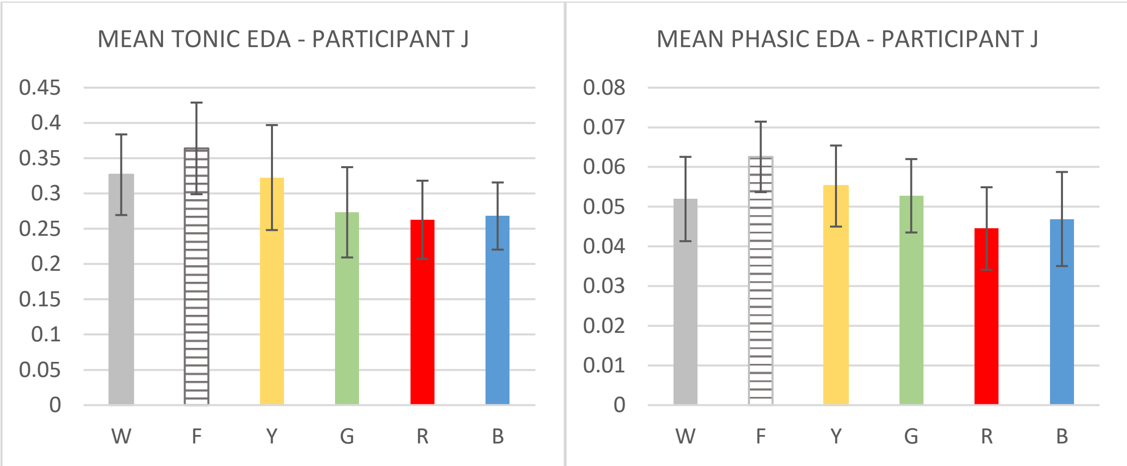


Figure 5. 20. Average Tonic EDA and Phasic EDA for Participant J under every light used, which lasted more than 30 seconds and which maintained the properties of the light intact, obtained during the case study.

The small difference in the results between all the light exposures and results of only the ones which accomplished the requirements evidenced the fact that the alteration on the duration of the properties of the light or the hue of the light can alter the impact the light has in the body responses. For this reason, for future discussion and comparisons, only the exposures which accomplish the requirements stated in Chapter Three will be used.

5.2.5. Comparison across participants: EDA

Tonic EDA:

In terms of the source of the light (fluorescent and LED light) and its influence on the tonic EDA, Fluorescent light was more arousing than White for three out of four participants – Participant F, Participant H and Participant J. Participant FX, on the contrary, was more aroused under White than under Fluorescent light. Table 5.21 shows under which source of the light - fluorescent (F) or LED (W) – the participants experienced lower (-) or higher (+) tonic arousal.

TONIC EDA

	W	F
F	(-)	(+)
FX	(+)	(-)
H	(-)	(+)
J	(-)	(+)

Figure 5. 21. Level of tonic arousal under Fluorescent (F) or White LED (W) for each participant (F, FX, H and J)

In terms of the influence of the colour of the light in the levels of tonic arousal, Table 5.22 shows the levels of tonic arousal observed under the different coloured light conditions for every participant. The levels of arousal are represented with four different symbols:

- The more arousing colour is represented with the symbol: (++).
- The less arousing colour is represented with the symbol: (--)
- The second more arousing colour is represented with the symbol (+).
- The second less arousing colour is represented with the symbol (-).

TONIC EDA

	Y	G	R	B
F	(++)	(-)	(+)	(- -)
FX	(- -)	(++)	(-)	(+)
H	(-)	(++)	(+)	(- -)
J	(++)	(+)	(- -)	(-)

Figure 5. 22. Level of tonic arousal under four different coloured lights (Yellow (Y), Green (G), Red (R) and Blue (B)) for each participant (F, FX, H and J).

On the one hand, according to the results of tonic EDA, results show that the effect of the colour of the light in the long-term arousal (tonic EDA) of participants F, H and J is similar in two aspects. First, the three participants were low aroused under Blue compared to other lights.

Second, Fluorescent light proved to be more arousing than White in the three cases. This finding indicates that the Fluorescent source of the light might have an arousing effect on these three participants. Participant FX, on the contrary, is highly aroused by Blue and not that much by Red, and White was more arousing than Fluorescent light.

More similarities were found between participants. For example, Yellow was low arousing for participants FX and H, especially compared to Green. In these two cases, the coloured light which was more arousing was Green. However, Yellow was highly arousing, more than any other coloured light for the Participant F and J.

These findings indicate that there might be many similarities in how the colour and source of the light influence the long-term arousal, but more research should be done to confirm this. Some lights such as Blue and Fluorescent light seem to have a broader effect on the participants. However, lights such as Yellow and Green LED are more unpredictable.

<u>Phasic EDA:</u>

In terms of the source of the light (fluorescent and LED) and its influence on the phasic EDA, Fluorescent light was more arousing than White for two out of four participants –Participant H and Participant J. Participant F and Participant FX, on the contrary, were more aroused under White than under Fluorescent light. Table 5.23 shows under which source of the light - fluorescent (F) or LED (W) – the participants experienced a fewer number of peaks (-) or greater number of peaks (+).

	PHASIC EDA	
	W	F
F	(+)	(-)
FX	(+)	(-)
H	(-)	(+)
J	(-)	(+)

Figure 5. 23. Level of phasic arousal under Fluorescent (F) or White LED (W) for each participant (F, FX, H and J).

In terms of the influence of the colour of the light in the levels of phasic arousal, Table 5.24 shows the levels of phasic arousal observed under the different coloured light conditions for every participant. The levels of arousal are represented with four different symbols:

- The colour which provokes a greater amount of peaks is represented with the symbol: (++).

- The colour which provokes fewer amount of peaks is represented with the symbol: (--)
- The second colour which provokes a greater amount of peaks represented with the symbol (+).
- The second colour which provokes fewer amount of peaks is represented with the symbol (-).

PHASIC EDA

	Y	G	R	B
F	(+)	(-)	(--)	(++)
FX	(- -)	(-)	(++)	(+)
H	(-)	(++)	(--)	(+)
J	(++)	(+)	(--)	(-)

Figure 5. 24. Level of phasic arousal under four different coloured lights (Yellow (Y), Green (G), Red (R) and Blue (B)) for each participant (F, FX, H and J).

According to the results of phasic EDA, results show that there are few similarities among the participants. Participants H and F reacted similarly to the LED lights, but Fluorescent light had a different effect on each of them. While Participant F and FX had more sudden reactions under White than under Fluorescent light, the contrary happened for Participant H, and J. Results also show that participants F, FX and H were more reactive to the environment under Green compared to Yellow. However, while Participant F, H and J were less reactive under Red than under any other light, participants FX was more reactive under Red than under Blue light.

Figure 5.25 shows the summary of the results of the tonic and phasic EDA of the four participants in which we can see the similarities and the differences between them which were mentioned above.

The sample was very small, so any results obtained in this case study can only be considered as preliminary results.

Many similarities were found between three out of four participants; however, the meaning of increased or decreased arousal might be different depending on the situation, although they might appear the same in the graphs. Consequently, the combination of the EDA information with other physiological signals such as the temperature of the tip of the nose is vital to understand if these similarities are, in fact, similar as well in meaning or they are only similar partially.

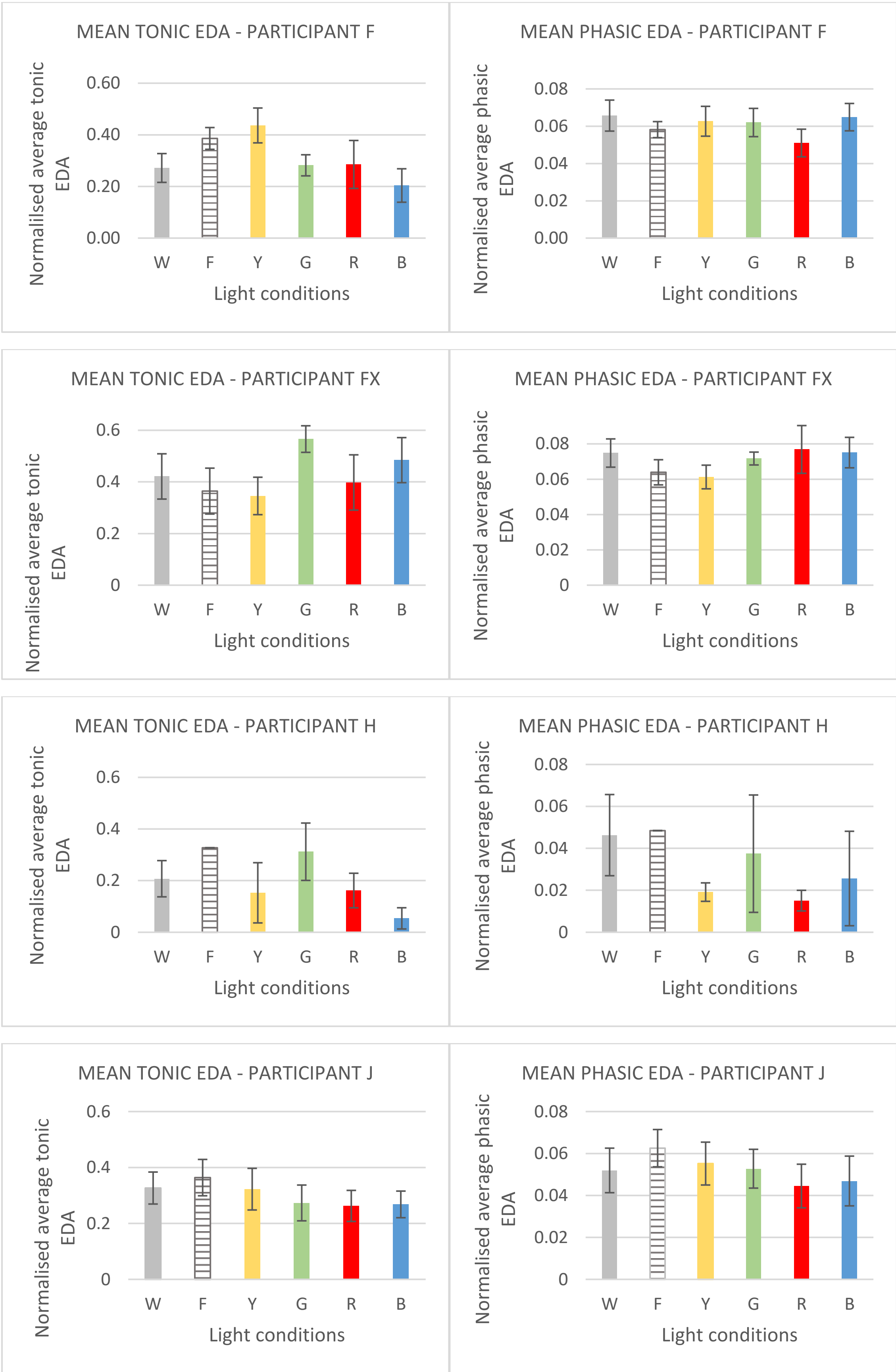


Figure 5. 25. Comparison of the mean EDA and the number of peaks under different light conditions obtained for all the participants during the case study.

5.3. Skin temperature

For many decades measuring physiological signals without attaching devices to the skin or interrupting experimental procedures to ask the participants how they feel has challenged human behaviour specialists. Thermography is a non-invasive technique employed in psychology to study autonomic physiological responses to emotions. As pointed out in Chapter Three, the temperature of the skin brings essential information about nonverbal behaviour, which is not subject to subjective interpretations as are some other measures, such as emotional valence (pleasant vs unpleasant). In a "fight or flight response", the temperature of the skin decreases because the blood rushes away from the outer layer of the body to fuel the muscles. Thus when an individual feels fear, the temperature tends to decrease, and when the individual feels excited, the temperature tends to increase. For this reason, thermal imaging of the face appears to be a promising tool for the study of the spontaneous responses to emotions (Merla et al., 2007).

A rise in temperature of at least 0.56 degrees Celsius in the forehead, the periorbital area or the face, in general, has been associated with arousing effects (Merla et al., 2007; Salazar-López et al., 2014). This study focuses the attention on the changes of temperature of the tip of the nose because thermal descent at the nose is linked to a greater sympathetic activation with fear, stress, telling lies or guilt (Ioannou, Gallese, & Merla, 2014; Panasiti et al., 2016). Panasiti et al. (2016) showed that the tip of the nose could be the most appropriate area of interest like a decrease of nasal temperature can be associated with stress, and an increase of the temperature can indicate a trait associated with a lie response. Merla et al. (2007) showed in a fear conditioning experiment that in people with Post Traumatic Stress Disorder (PTSD) their nose cooled by up to 2 degrees Celsius in stressing situations and took longer to recover its average temperature than participants without PTSD.

Moline et al. (2018) found that the change in nasal temperature is affected by the anxiety and mental load involved in the process of lying. In their study, the temperature of the nose tended to decrease during lying around 1 degree Celsius on average due to the sympathetic nervous system activation and arterial vasoconstriction caused by the anxiety that lying implies. However, the temperature of the forehead maintained constant. The level of state anxiety measured using the STAI (The State-Trait Anxiety Inventory) increased from 24.0 point-scale (SD= 7.3) to 35.1 (SD= 8.2) after telling a lie. The researchers called this phenomenon "Pinocchio effect", and they proved that this phenomenon exists, but it is unclear if it is due to the lie itself or a consequence of the anxiety caused by lying.

According to a study carried out at the University of Nottingham's Institute for Aerospace Technology (IAT), together with academic staff from Bioengineering and human factors research groups found that a decrease in nasal temperature and facial temperature, in general, can also be linked to mental workload when performing demanding tasks. The drop in temperature responds to a diversion of blood flow from the face to the cerebral cortex when the mental demand increases (Marinescu, Sharples, & Ritchie, 2018).

Based on the previous pieces of work, and as explained in Chapter Three, thermography was used to identify changes in temperature at the tip of the nose in the four participants who participated in the experiment. The nose, particularly, the tip, proved to be the best place of the body to record changes related to emotional and cognitive states but, moreover, the nose is a straightforward point to hit the target when somebody needs to take the picture and evaluate a point, especially when the participant might be moving. Temperature measurements from larger parts of the body like the forehead can vary a lot if the studied point is not always the same. Measuring the tip of the nose might be more accurate than other parts of the body, and for this reason, it was the spot chosen for the case study. The tip of the nose, therefore, proved to be an objective, non-invasive and non-obtrusive tool to gather complementary physiological information about the participants

For this purpose, a compact thermal camera FLIR C3 Pocket size was used. Pictures were taken every 30 seconds, obtaining an average of 30-32 pictures per session and every picture stores 4,800 individual thermal measurements that can be analysed, so having a small and easy target to analyse such as the tip of the nose is vital for excellent precision. As mentioned in Chapter Three, low-quality images or images in which the participant appeared to be moving were removed from the data set to avoid contaminated data. FLIR Tools software was used to identify and analyse the points of interest of every picture (the tip of the nose) (Chapter Four).

The thermal imaging results for each participant are now described, first by day and then across days.

5.3.1. Participant F:

Analysis per day:

Influence of the colour of the light in the temperature

All the data about the temperature of the tip of the nose for Participant F can be found in Appendix G and show the mean temperature of the tip of the nose according to the light colour and the day of the experiment for Participant F. Results show that the temperature of the tip of the nose seemed to change depending on the colour of the light set during the same day. This finding could indicate that the colour of the light seemed to have an impact on the temperature of the tip of the nose. However, these changes on temperature might not be always consistent.

Patterns observed across the days and consistency of the results

Only 41.67% of the times (5 out of 12 times), the trend-line of the temperature change related to the different lights was upward. For example, Figure 5.26 shows the upward trendline of the temperature of the tip of the nose, which increases over the session on day 7.

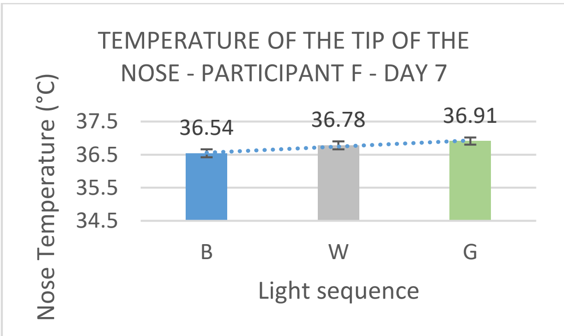


Figure 5. 26. Upward trend-line of the temperature of the tip of the nose for Participant F under Blue (B), White (W) and Green (G), obtained on day 7.

As observed in the EDA measurements, these results could call into question the idea that there is a consistent influence of the colour of the light on the temperature of the tip of the nose. As will be discussed in Chapter Eight, this fact can respond to different reasons: whether the colour or the source of the last light of the light sequence of the session is which induces the increase in arousal, or the levels of excitation (the body responds to excitation by increasing the temperature of the tip of the nose) might increase during the session, independently of the light sequence, as will be discussed in Chapter Eight.

Nevertheless, this upward tendency does not occur in all the sessions. Figure 5.27 shows how the participant experienced a higher temperature on the tip on the nose at the beginning of the session under Green light (37.35°C), decreased under Red (36.8°C) and increased a little bit again under Yellow light (37.1°C).

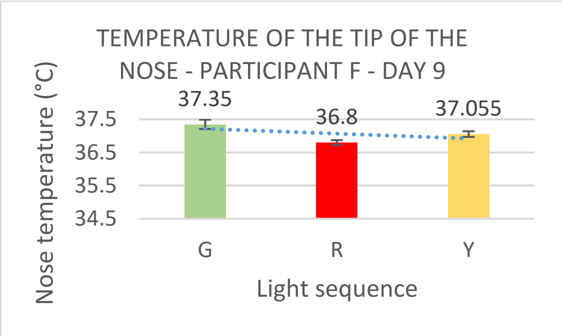


Figure 5. 27. Downward trend-line of the temperature of the tip of the nose for Participant F under Green (G), Red (R) and Yellow (Y), obtained on day 9.

There were other times, such as the session on day 14, that there was no significant change on the temperature of the tip of the nose regarding the colour of the light. Figure 5.28 shows that the temperature of the tip of the nose on day 14 remained constant during the whole session. In this case, results suggest that the colour of the light did not impact on the temperature of the tip of the nose.

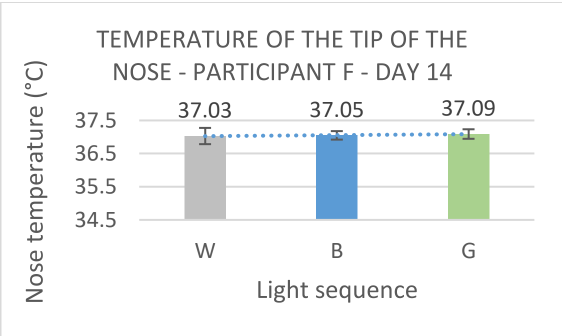


Figure 5. 28. Constant trend-line of the temperature of the tip of the nose for Participant F under White (W), Blue (B) and Green (G), obtained on day 14.

On day 7 (Figure 5.26) and day 14 (Figure 5.28) show that the fluctuations were not always consistent with the source or colours of the light, as on day 7 there was a difference of 0.4°C between Blue and Green, while on day 14 there was only a small difference of 0.04°C.

Although the fluctuations of temperature under different light conditions do exist, the variations might be too small and more samples would be necessary to confirm whether there exists an influence on the temperature of the nose, for Participant F. These findings might indicate that there might not be a consistent and robust impact on the temperature of the nose due to the colour of the light and, for instance, the impact could exist but the direction of it cannot be predictable.

Influence of the source of the light in the temperature: Fluorescent light vs White LED

Participant F was exposed to both lights in the same session three times on days 4, 11 and 12 (Figure 5.29). Even though the sequences were different, results show the temperature on the tip of the nose was lower under White than under Fluorescent light the three days. This result indicates that the source of the light could impact the temperature of the tip of the nose for Participant F, and that White induces lower temperature of the tip of the nose than Fluorescent light.

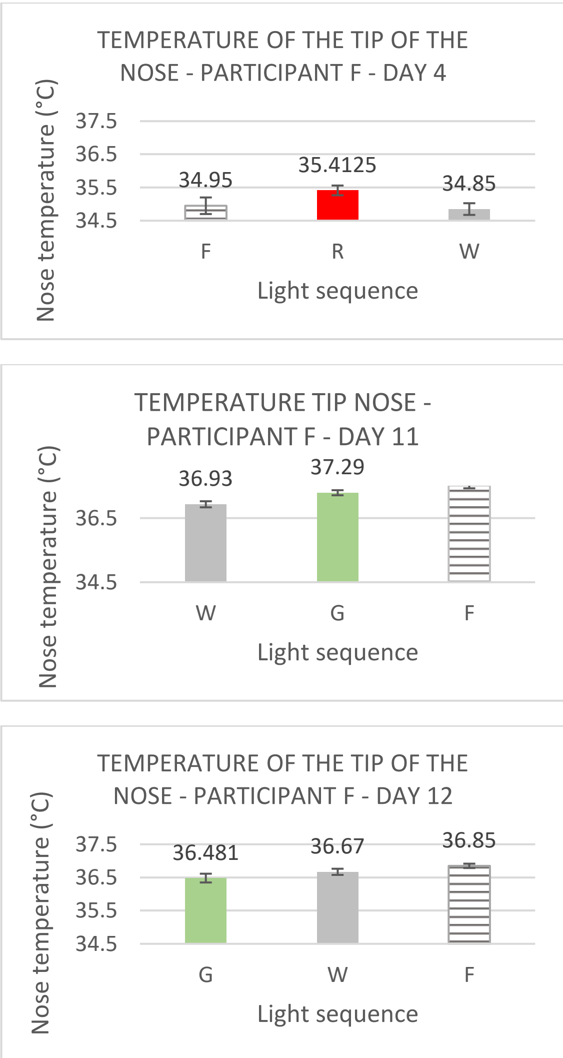


Figure 5. 29. Average temperature of the tip of the nose for Participant F under White (W) and Fluorescent light (F), among other lights such as Red (R) and Green (G), obtained on days 4, 11 and 12.

Summary all days Participant F:

Figure 5.30 shows the average temperature of the tip of the nose under different light conditions obtained for Participant F during the case study. Results show that the participant experienced a different mean of the temperature of the tip of the nose depending on the lights used (W=36.55°C, Range 34.2-38.5°C; F=36.57°C, Range 34.2-38.1°C; Y=36.52°C, Range 34.2-37.6°C; G=36.79°C, Range 35.2-38.2°C; R=36.39 °C, Range 34.6-37.4°C; B=36.65 °C, Range 35.1-37.9°C). The average temperature of the tip of the nose remained similar under Fluorescent light and Yellow, and it is higher during Green and Blue exposures. The lowest averages of temperatures of the tip of the nose were observed under Yellow and Red lights. The difference between the highest values (G=36.79 °C, Range 35.2-38.2°C) and the lowest (R=36.39 °C, Range 34.6-37.4°C) was 0.40 degrees Celsius.

These findings indicate that the colour of the light could have an impact on the temperature of the tip of the nose of the participant. According to previous work, these findings could indicate that Participant F might feel more anxious under Red due to the low-temperature rates (Merla et al., 2007) and, for instance, might feel more comfortable under Green due to the high-temperature rates, followed by Blue. However, it would be important to compare it with other measures and to have a more significant sample for this participant to elucidate whether these results depend on the colour and source of the light.

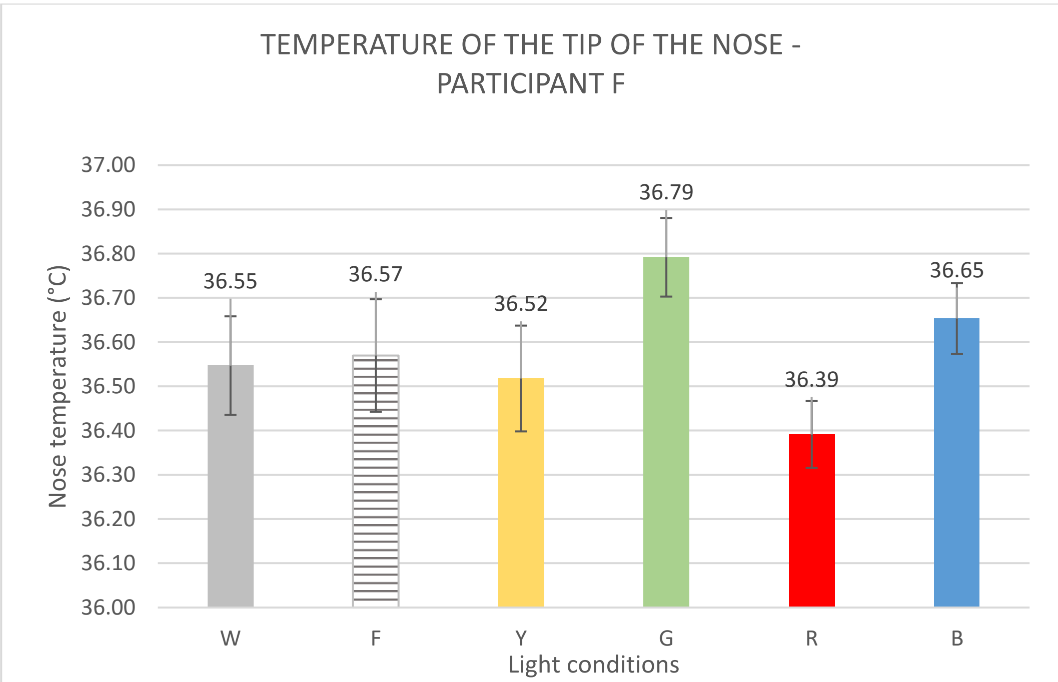


Figure 5. 30. Average temperature of the tip of the nose for Participant F under every light used, obtained during the case study.

5.3.2. Participant FX:

Analysis per day:

Influence of the colour of the light in the temperature

All the data about the temperature of the tip of the nose for Participant FX can be found in Appendix G and show the mean temperature of the tip of the nose according to the light colour and the day of the experiment for Participant FX. Results show that the temperature of the tip of the nose seemed to change depending on the colour of the light set during the same day, although the variations can be very small in some cases. This finding indicates that the colour of the light could have an impact on the temperature of the tip of the nose but further research is necessary to determine if these fluctuations are consistent and significant or not.

Patterns observed across the days and consistency of the results

In 41.67% of the times (5 out of 12 times), the trend-line of the temperature change related to the different lights is upward. For example, Figure 5.31 shows the upward trendline of the temperature of the tip of the nose, which increases over the session on day 7.

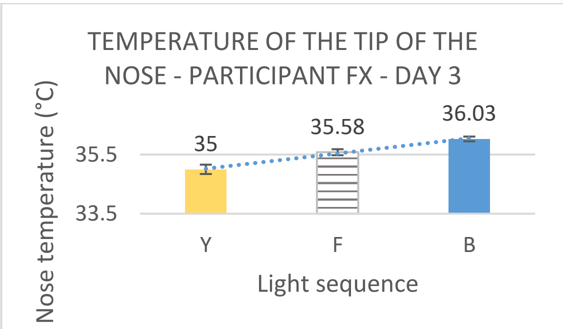


Figure 5. 31. Upward trend-line of the temperature of the tip of the nose for Participant FX under Yellow (Y), Fluorescent light (F) and Blue (B), obtained on day 3.

As will be discussed in Chapter Eight, this fact can respond to different reasons: whether the colour or the source of the last light of the light sequence of the session is which induces the increase in arousal, or the levels of excitation (the body responds to excitation by increasing the temperature of the tip of the nose) might increase during the session, independently of the light sequence.

These results indicate that there might not be an influence of the colour of the light in the temperature of the tip of the nose. The fluctuations seemed to be not always consistent with the source or colours of the light and, for instance, the impact might exist, but the direction of it cannot be predictable.

Nevertheless, this upward tendency does not occur in all the sessions. Figure 5.32 shows how the participant experienced a higher temperature on the tip on the nose at in the middle of the session under Fluorescent light (35.95°C).

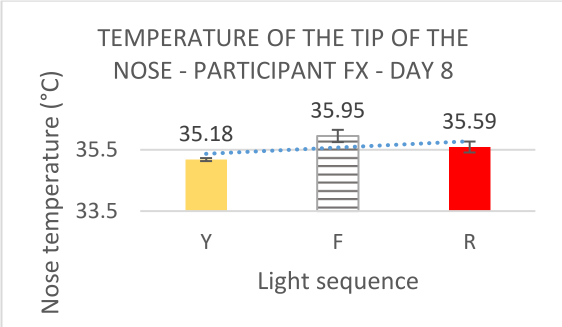


Figure 5. 32. Average temperature of the tip of the nose for Participant FX under Yellow (Y), Fluorescent light (F) and Red (R), obtained on day 8.

Many results observed for Participant FX were consistent. For example, when comparing temperature under Fluorescent and Yellow lights, results were consistent. Both lights were set together on day 3 (Figure 5.31) and day 8 (Figure 5.32) and the temperature of the tip of the nose was around half-degree Celsius higher under Fluorescent than under Yellow light.

Another example of consistency can be observed when comparing measures under Blue and Green. Both lights were set together on days 2, 6, 7 and 14. Figure 5.33 shows that temperature measurements were higher under Green than under Blue all days except day 14.

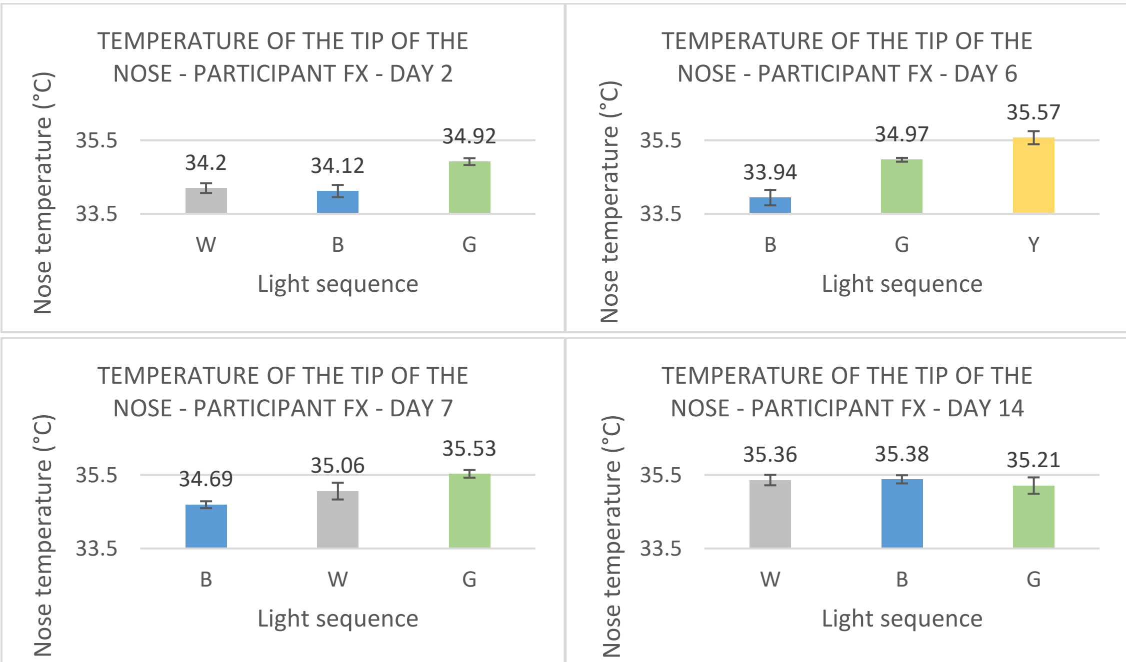


Figure 5. 33. Average temperature of the tip of the nose for Participant FX under Green (G) and Blue (B), among other lights such as White (W) and Yellow (Y), obtained on days 2, 6, 7 and 14.

In some cases, though, the variations of temperature in the different light conditions were unusually small or were not consistent. These results indicate that the temperature of the tip of the nose might not be always consistent and that further research should be necessary. For example, these inconsistencies and small variations can be detected when comparing temperature measurements under Red and Fluorescent. Figure 5.34 shows that on day 4, the variation between both lights was almost inexistent, while on day 8, the temperature was higher under Fluorescent than under Red.

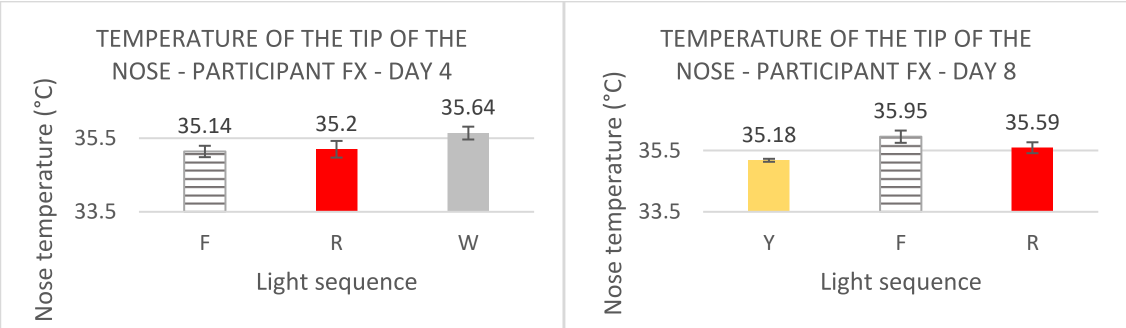


Figure 5. 34. Average temperature of the tip of the nose for Participant FX under Red (R) and Fluorescent (F), among other lights such as White (W) and Yellow (Y), obtained on days 4 and 8.

Figure 5.35 shows these inconsistencies and small variations when comparing results under Red and Yellow. On day 9, the thermal variation between both lights was inexistent; on day 10, the temperature was higher under Yellow; and on day 5, it was slightly higher under Red.

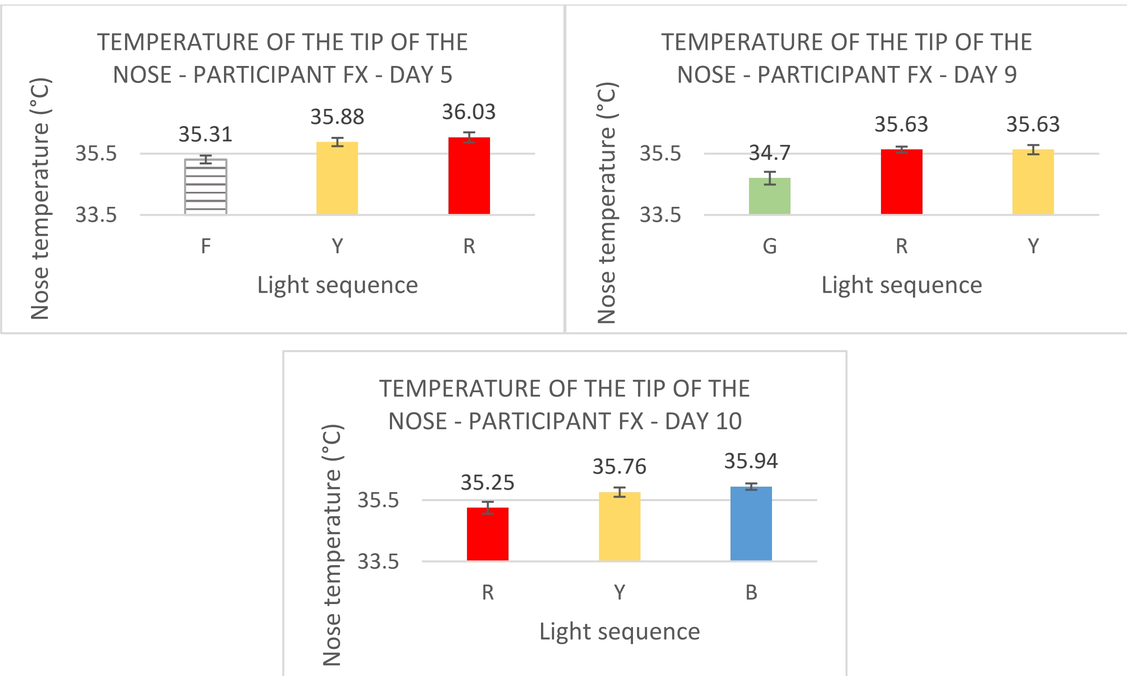


Figure 5. 35. Average temperature of the tip of the nose for Participant FX under Red (R) and Yellow (Y), among other lights such as Fluorescent (F), Green (G) and Blue (B), obtained on days 5, 9 and 10.

These results suggest that further research should be necessary.

Influence of the source of the light in the temperature: Fluorescent light vs White LED

Participant FX was exposed to both lights in the same session on days 4 and 12 (Figure 5.36), and results are contradictory. On day 4, the temperature was higher under White than under Fluorescent; on day 12, the temperature was higher under Fluorescent than under White.

These results indicate that the source of the light could not impact the temperature of the tip of the nose for Participant FX consistently. However, the sample is too small to conclude this and further research should be necessary.

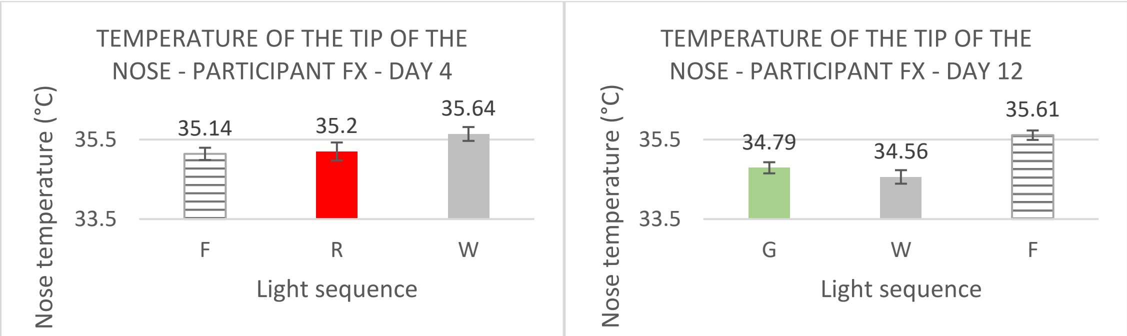


Figure 5. 36. Average temperature of the tip of the nose for Participant FX under White (W) and Fluorescent light (F), among other lights such as Red (R) and Green (G), obtained on days 4 and 12.

Summary all days:

Figure 5.37 shows the average temperature of the tip of the nose under different light conditions obtained for Participant FX from the two-month experiment. The figure shows that the participant experienced a different average of temperature of the tip of the nose depending on the lights used (W=34.87°C, Range 33.2-36.2°C; F=35.53°C, Range 34.5-36.6°C; Y=35.4°C, Range 33.9-36.5°C; G=35.23°C, Range 33.7-36.4°C; R=35.30°C, Range 33.2-36.6°C; B=35.33°C, Range 33.4-36.6°C). The average temperature of the tip of the nose was higher under Fluorescent light, followed by Yellow, than under any other light, and it decreased under White. The difference between the highest values (F=35.53°C, Range 34.5-36.6°C) and the lowest (W=34.87°C, Range 33.2-36.2°C) was 0.66 degrees Celsius.

These findings indicate that the colour of the light could have an impact on the temperature of the tip of the nose of the participant. According to previous work, these findings indicate that Participant FX might feel more anxious under White conditions due to the decrease on temperature of the tip of the nose and might feel more comfortable under Fluorescent light conditions, followed by Yellow due to the increase in temperature of the tip of the nose (Merla et al., 2007). However, it would be fundamental to have a more significant sample to elucidate whether these results depend on the colour and source of the light because the daily analysis presented many inconsistencies.

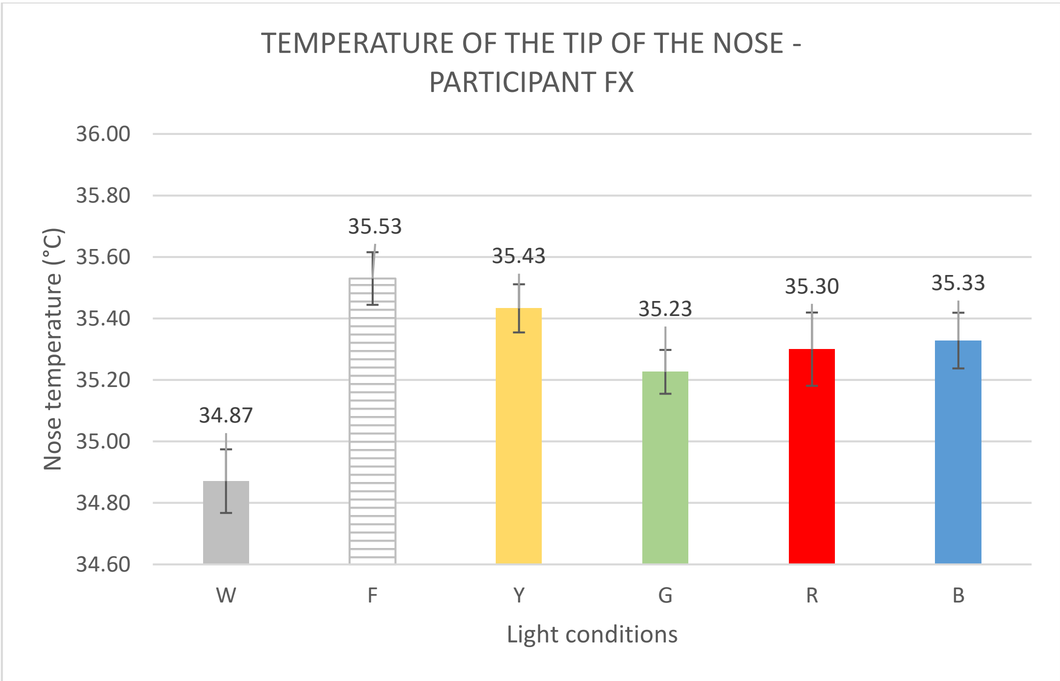


Figure 5. 37. Average temperature of the tip of the nose for Participant FX under every light used, obtained during the case study.

5.3.3. Participant H:

Analysis per day:

Influence of the colour of the light in the temperature

All the data about the temperature of the tip of the nose for Participant H can be found in Appendix G and show the mean temperature of the tip of the nose according to the light colour and the day of the experiment for Participant H. Results show that, even though the temperature of the tip of the nose seemed to change depending on the colour of the light, the difference might not be consistent or significant. Unfortunately, the sample is too small to predict responses in the future.

Patterns observed across the days and consistency of the results

It is not possible to observe either a specific trend-line or consistency between colours because the sample is too small. There are not many repetitions to observe consistency on the fluctuations. On day 4 (Figure 5.38), the temperature of the tip of the nose increases over time.

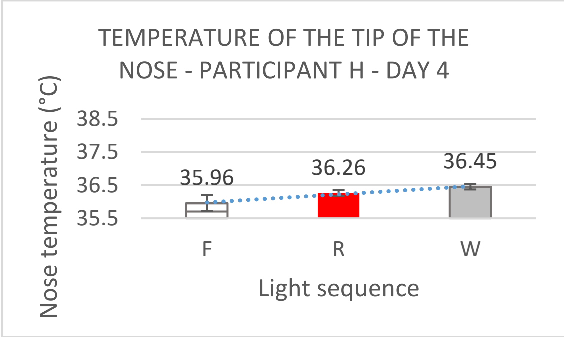


Figure 5. 38. Upward trend-line of the temperature of the tip of the nose for Participant H under Fluorescent light (F), Red (R) and White (W) obtained on day 4.

However, on day 14 (Figure 5.39), the temperature of the tip of the nose descended over time.

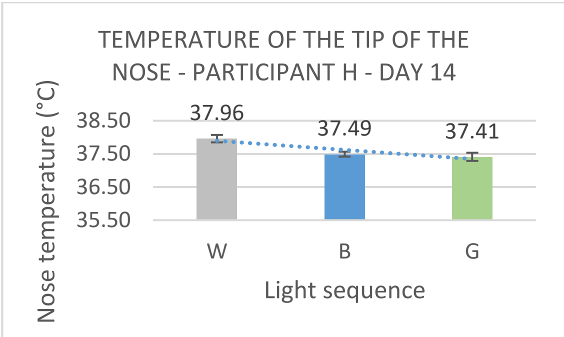


Figure 5. 39. Downward trend-line of the temperature of the tip of the nose for Participant H under White (W), Blue (B) and Green (G) obtained on day 14.

On days 7 and day 8 (Figures 5.40 and 5.41, respectively), for example, there was not an especific trendline. On day 7, the highest temperature was observed in the middle of the session under White; on day 8, the temperature was lower during White compared to Blue light. On day 8, the lowest temperature was observed in the middle of the session under Red.

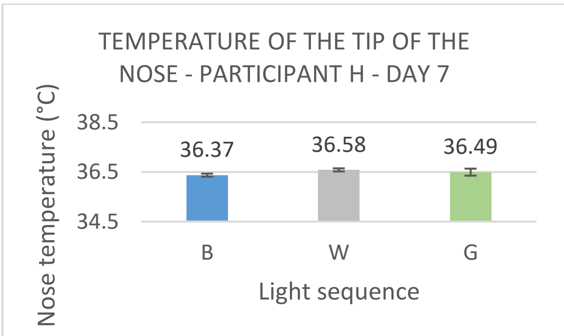


Figure 5. 40. Average temperature of the tip of the nose for Participant H under Blue (B), White (W) and Green (G) obtained on day 7.

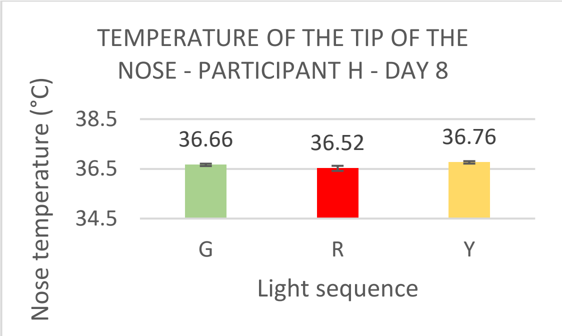


Figure 5. 41. Average temperature of the tip of the nose for Participant H under Green (G), Red (R) and Yellow (Y) obtained on day 8.

These results indicate that there could not be a significant impact on the temperature of the nose due to the colour of the light. The fluctuations are not related to the source or colours of the light and, for instance, the impact cannot be predictable.

Influence of the source of the light in the temperature: Fluorescent light vs White LED

The limited results obtained from Participant H are not enough to suggest any difference between Fluorescent light or White light. The only day in which both lights were set together was on day 4 (Figure 5.42), and Fluorescent light recorded lower temperature measurements than White LED. However, this result can be merely anecdotic.

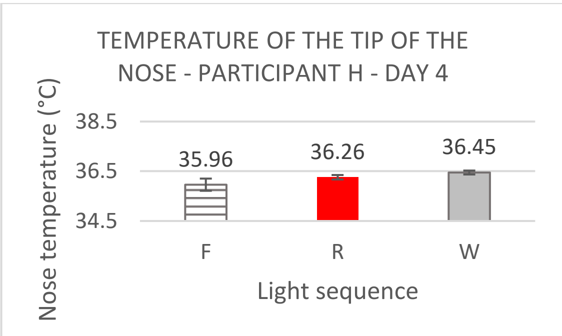


Figure 5. 42. Average temperature of the tip of the nose for Participant H under Fluorescent light (F), Red (R) and White (W) obtained on day 4.

Summary all days:

Figure 5.43 shows the average temperature of the tip of the nose under different light conditions obtained for Participant H from the two-month experiment. The participant experienced a different average of temperature of the tip of the nose depending on the lights used (W=36.69℃, Range 35.8-38.2℃; F=36.16℃, Range 34.8-36.8℃; Y=36.47℃, Range 35.6-37.1℃; G=36.73℃, Range 35.7-38.1℃; R=36.26℃, Range 35.6-36.9℃; B=36.63℃, Range 34.9-37.9℃). The average temperature of the tip of the nose was higher and similar under White and Green, and it was lower during Fluorescent light and Red LED lights. The difference between the highest values (G=36.73℃, Range 35.7-38.1℃) and the lowest (F=36.16℃, Range 34.8-36.8℃) was 0.57 degrees Celsius.

These findings seemed to indicate that the source and the colour of the light could have an impact on the temperature of the tip of the nose of the participant. However, as already mentioned in the daily analysis of Participant H, these results can be merely anecdotic because the sample of sessions was very small to see consistency in the results. This is why comparing the daily analysis, and the average can be informative, and it is because the information that the average of the data provided can hide many nuances that are more present in the daily analysis. According to previous work, these findings could indicate that Participant H might feel more anxious under Fluorescent light conditions due to the low temperature of the tip of the nose observed, and might feel more comfortable under Green LED conditions, followed by White and Blue due to the high temperature of the tip of the nose (Merla et al., 2007). However, we would need to consider that the sample was too small to rely on the results and use them to predict behaviours in the future. It would be necessary to obtain more samples to have a more accurate understanding of his behaviour.

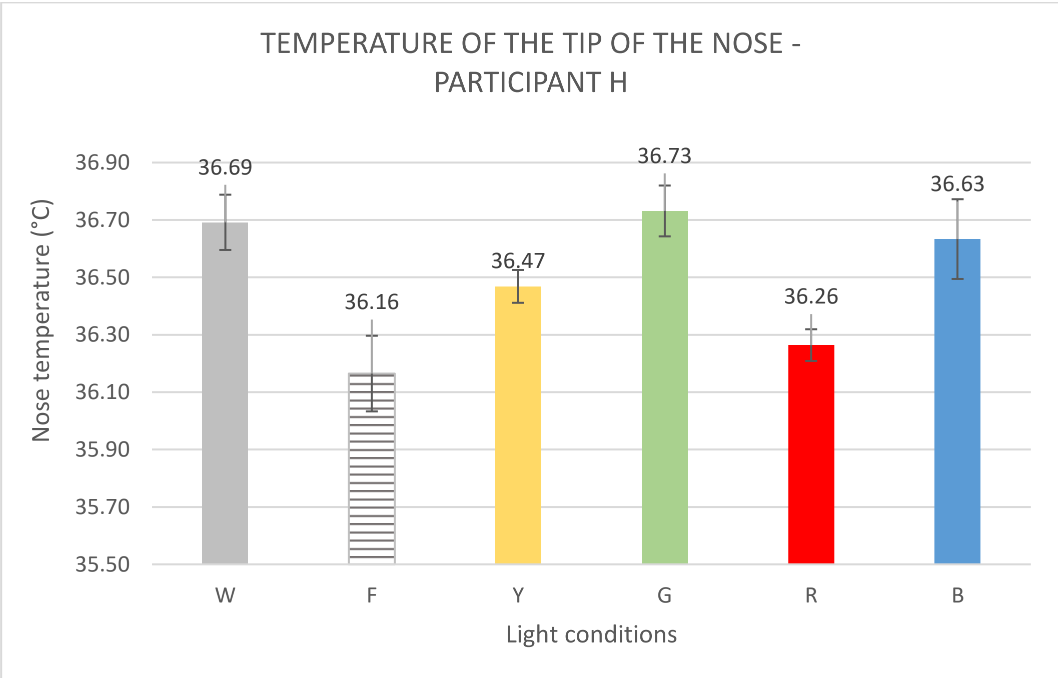


Figure 5. 43. Average temperature of the tip of the nose for Participant H under every light used, obtained during the case study.

5.3.4. Participant J:

As previously mentioned, the sessions of Participant J suffered alterations compared to the other participants because the participant wanted to change the colour of the light often. On the one hand, as Participant J sometimes asked for a change in the colour of the light, he experienced light exposures of less than 30 seconds, symbolised with the symbol (*) which might not show alterations in the physiological signals such as the temperature of the tip of the nose; therefore, these values might not be comparable to the ones obtained during longer exposures (Caldwell & Jones, 1984). Nevertheless, even though these exposures cannot be compared to the longer exposures, they will also be shown in this chapter for future discussion.

On the other hand, Participant J also asked for darker versions of the colour blue, symbolised with the symbol (+). The new tone was obtained by changing only the hue of the light, maintaining the saturation and the intensity, as it happened with the rest of the light exposures. As seen in Chapter Two, different values of the properties of the colour, such as hue can influence the individual differently (Wilms & Oberfeld, 2016). Consequently, even though the exposures with new different hues will be considered as "Blue" for easier comprehension, the changes will be noted so any alterations in the results could be considered and discussed in the future. As the property of the hue was different, results might be less significant, comparatively speaking.

Analysis per day:

Influence of the colour of the light in the temperature

All the data about the temperature of the tip of the nose for Participant J can be found in Appendix G and show the mean temperature of the tip of the nose according to the light colour and the day of the experiment for Participant J. Results show that the temperature of the tip of the nose changed depending on the colour of the light set during the same day. This finding indicates that the colour of the light could have an impact on the temperature of the tip of the nose.

Patterns observed across the days and consistency of the results

Only in 36.36% of the times (4 out of 11 times), the trend-line of the temperature change related to the different lights is upward. For example, one of these four days was day 10. Figure 5.44 shows the upward trend-line observed on day 10.

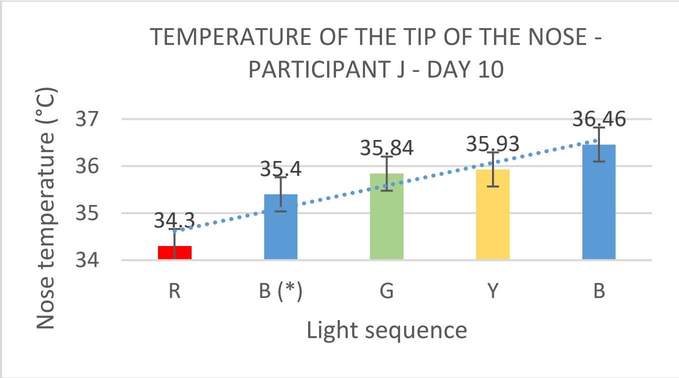


Figure 5. 44. Average temperature of the tip of the nose for Participant J under Red (R), Blue (B), Green (G) and Yellow (Y) obtained on day 10.

However, the trend-line of the temperature change related to the different lights observed in other sessions did not present any particular pattern. For example, Figure 5.45 shows that on day 3, Participant J wanted to change the colour of the light often and this fact not only allowed to see there was no pattern but also that the temperature of the tip of the nose was consistent with the colour of the light. The temperatures observed under Yellow and Fluorescent were always consistent, no matter when they were set during the session. The temperatures observed under Blue were not as consistent as the ones observed under Yellow and Fluorescent, but the short duration of the Blue exposures might influence the results.

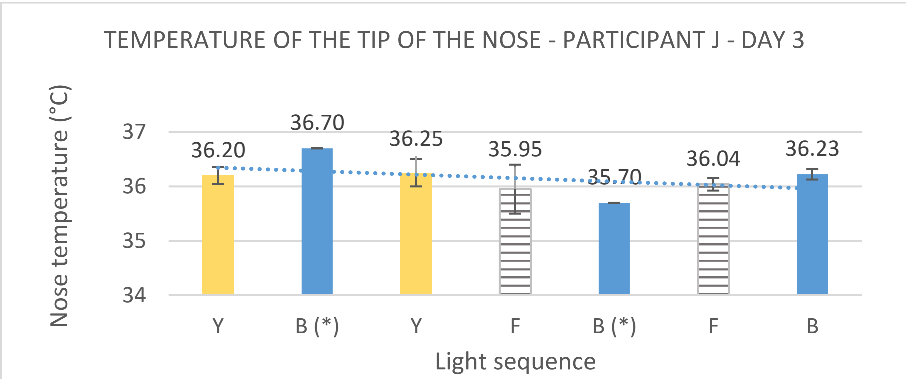


Figure 5. 45. Average temperature of the tip of the nose for Participant J under Yellow (Y), Blue (B) and Fluorescent light (F) obtained on day 3.

These results indicate that there could be an impact on the temperature of the tip of the nose due to the colour of the light and that this impact was consistent.

Influence of the source of the light in the temperature: Fluorescent light vs White LED

Participant J was exposed to both lights in the same session on days 4, 9 and 11 (Figure 5.46). Even though the sequences were different, results show that on day 4 and 11, the temperature on the tip of the nose was lower under White light. However, on day 9, measurements under White were higher than under Fluorescent light.

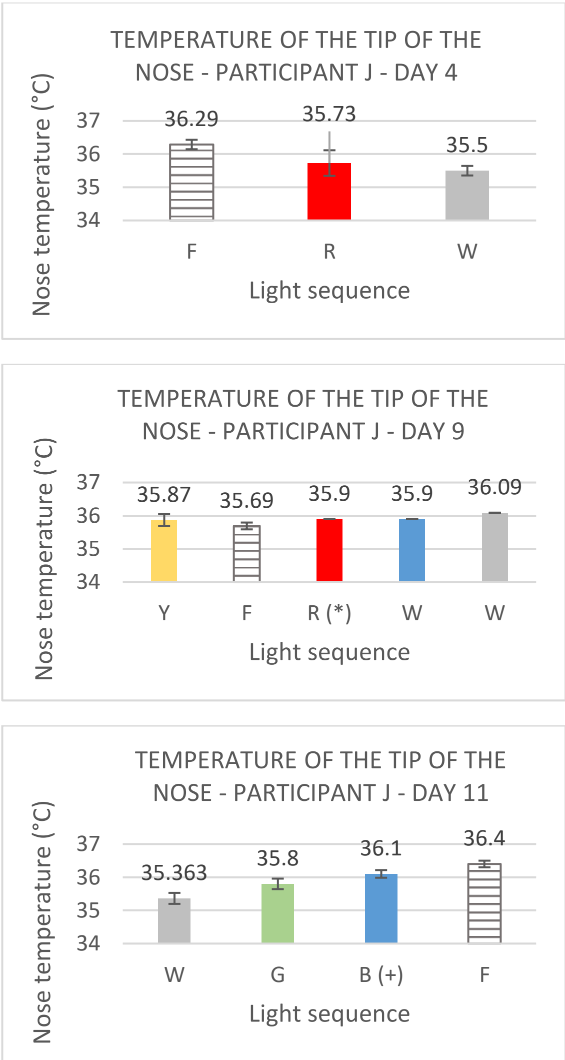


Figure 5. 46. Average temperature of the tip of the nose for Participant J under White (W), Green (G), Blue (B) and Fluorescent light (F) obtained on days 4, 9 and 11.

Summary all days:

Figure 5.47 shows the average temperature of the tip of the nose under different light conditions obtained for Participant J from the two-month experiment. The participant experienced a different average of temperature of the tip of the nose depending on the lights used (W=35.95℃, Range 34.7-36.7℃; F=35.94℃, Range 34.7-36.9℃; Y=36.07℃, Range 34.3-37℃; G=36.13℃, Range 35-37.4℃; R=34.85℃, Range 34.3-37℃; B=36.08℃, Range 34.3-36.9℃). The average temperature of the tip of the nose remained higher and similar under Green, Yellow and Blue. The temperature of the tip of the nose experienced a dramatic drop during Red. The difference between the highest values (G=36.13℃, Range 35-37.4℃) and the lowest (R=34.85℃, Range 34.3-37℃) was 1.28 degrees Celsius.

These findings indicate that the colour of the light could have an impact on the temperature of the tip of the nose of the participant, but the source could not have a substantial impact on the temperature of the tip of the nose, as the temperature on the tip of the nose under White and Fluorescent light was almost the same. According to previous work, these findings could indicate that Participant J might feel more anxious under Red conditions than any other light due to the low-temperature measurements (Merla et al., 2007). Participant J might feel more excited or calm under Green, Yellow and Blue conditions. Other physiological signals, such as arousal might determine whether he is feeling one feeling or the other.

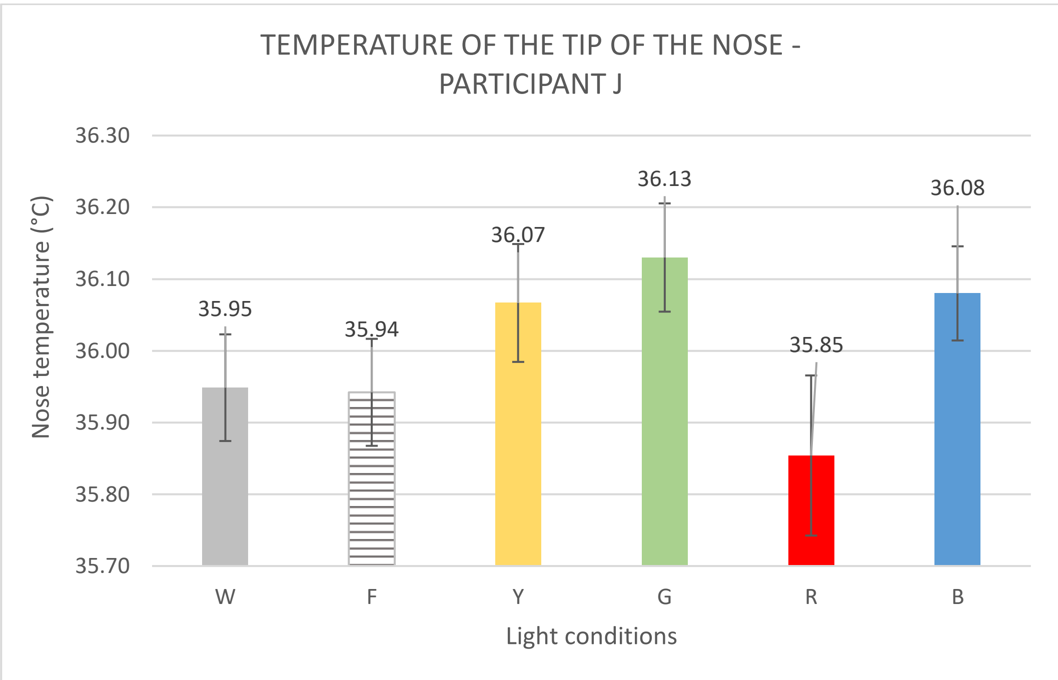


Figure 5. 47. Average temperature of the tip of the nose for Participant J under every light used, obtained during the case study.

However, as mentioned before, participant J wanted to change the colour of the light often and even the tone of the light. This attitude resulted in variations of time and hue. As previously seen in the literature, both factors can have a significant influence on the results. For this reason, Figure 5.48 shows the mean temperature of the tip of the nose for the light exposures collected along with the two-month experiment for Participant J, avoiding all the exposures shorter than 30 seconds and the exposures which altered the properties of the light.

The only lights affected by these two variations were the lights Green, Red, and Blue. Results on the temperature of the tip of the nose are different depending on the colour of the light. This finding indicates that the colour of the light could have an impact on the temperature of the tip of the nose of the participant.

As seen in the previous calculations, results indicate that Average temperature of the tip of the nose remained higher and similar under Green, Yellow and Blue and that the temperature of the tip of the nose experienced a dramatic drop during Red light.

When omitting the light exposures, which lasted less than 30 seconds and the light exposures, which altered the hue of the light, results show very similar results. The average temperature of the tip of the nose remained higher and similar under Green, Yellow and Blue and the temperature of the tip of the nose experienced a dramatic drop during Red. The difference between the highest values (G=36.13℃, Range 35-37.4℃) and the lowest (R=35.87℃, Range 34.3-37℃) was 0.26 degrees Celsius.

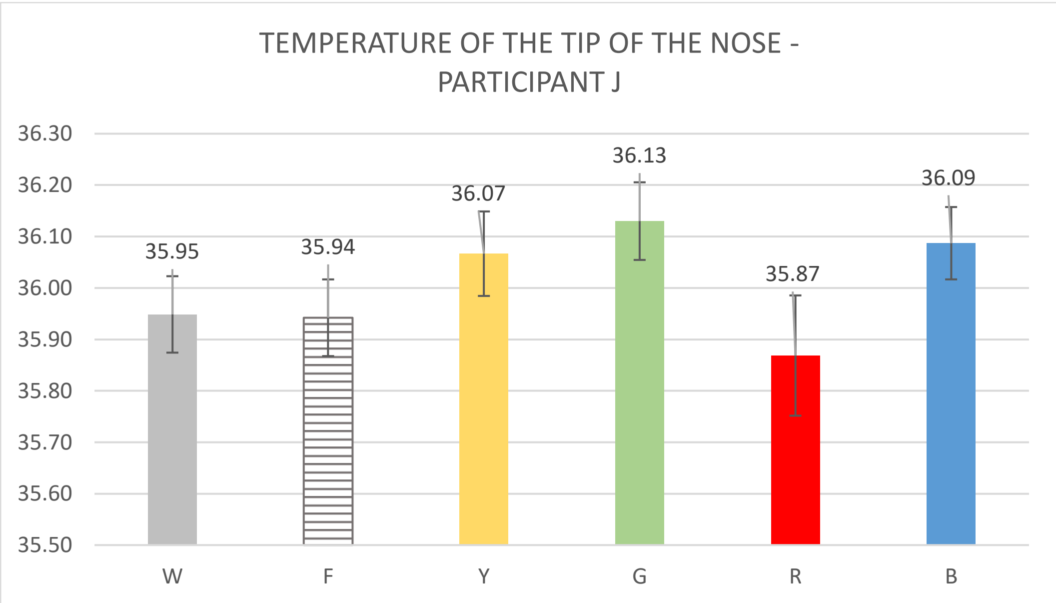


Figure 5. 48. Average temperature of the tip of the nose for Participant J under every light used, which lasted more than 30 seconds and which maintained the properties of the light intact, obtained during the case study.

In this case, although the sample is very small, the duration of the exposures and the hue seemed to moderately alter the impact the light has in the temperature of the tip of the nose, although the relationship of the results between the lights remains similar.

5.3.5 Comparison across participants: temperature of the tip of the nose

In terms of the source of the light (fluorescent and LED) and its influence on the temperature of the tip of the nose, two out of four participants registered the same temperature on the tip of the nose under Fluorescent light, and White – Participant F and Participant J. Participant FX registered higher temperature under Fluorescent light than under White, and results of Participant H were the opposite, registering more temperature under White than under Fluorescent light. Table 5.49 shows under which source of the light - fluorescent (F) or LED (W) – the participants experienced lower (-) or higher (+) temperature of the tip of the nose.

	TEMPERATURE	
	W	F
F	(=)	(=)
FX	(-)	(+)
H	(+)	(-)
J	(=)	(=)

Figure 5. 49. Level of the temperature of the tip of the nose under two different sources of the light (Fluorescent (F) or LED (W)) for each participant (F, FX, H and J).

In terms of the influence of the colour of the light in the temperature of the tip of the nose, Participant F, H and J had similar fluctuations in the temperature of the tip of the nose depending on any of the coloured lights. Even though the fluctuations might vary more or less depending on the case, they are consistent with each other. They had a higher temperature of the tip of the nose under Green, followed by Blue and Yellow and finally, Red. Participant FX, on the contrary, had almost opposite results. Table 5.50 shows the temperature of the tip of the nose observed under the different coloured light conditions for every participant. The levels of temperature are represented with four different symbols:

- The colour which presented higher temperature is represented with the symbol: (++).
- The colour which presented lower temperature is represented with the symbol: (--)
- The second colour which presented higher temperature is represented with the symbol (+).

- The second colour which presented lower temperature is represented with the symbol (-).

TEMPERATURE

	Y	G	R	B
F	(-)	(++)	(- -)	(+)
FX	(++)	(- -)	(+)	(-)
H	(-)	(++)	(- -)	(+)
J	(-)	(++)	(- -)	(+)

Figure 5. 50. Level of the temperature of the tip of the nose under four different coloured lights (Yellow (Y), Green (G), Red (R) and Blue (B)) for each participant (F, FX, H and J).

As observed, some similarities were found in the results. First, three participants presented similar temperatures of the tip of the nose under Yellow compared with Fluorescent light, although the temperature of the tip of the nose of Participant J is a little bit higher than the rest. Participant F, H and J had similar fluctuations in the temperature of the tip of the nose depending on any of the coloured lights. Even though the fluctuations might vary more or less depending on the case, they are consistent with each other. They had a higher temperature of the tip of the nose under Green, followed by Blue and Yellow. Nevertheless, the temperature of the tip of the nose of Participant FX fluctuated differently compared to the other participants. While the temperature tended to increase under Green and Blue and to decrease under Red, in the case of Participant FX it was the contrary: the temperature decreased under Green and Blue and increased under Red and Yellow.

These results indicate that the colour and source of the light could have a similar influence as the temperature of the tip of the nose across the participants. For instance, this information might be used in the future to assess the environment of these children. However, it is not possible to make a general recommendation about this: these results cannot be applied to Participant FX as his results deviated from the rest, whose temperature measures are exceptionally lower in general, compared to the other participants.

Figure 5.51 shows the summary of the results of the temperature of the tip of the nose of the four participants in which we can see the similarities and the differences between them which were mentioned above.

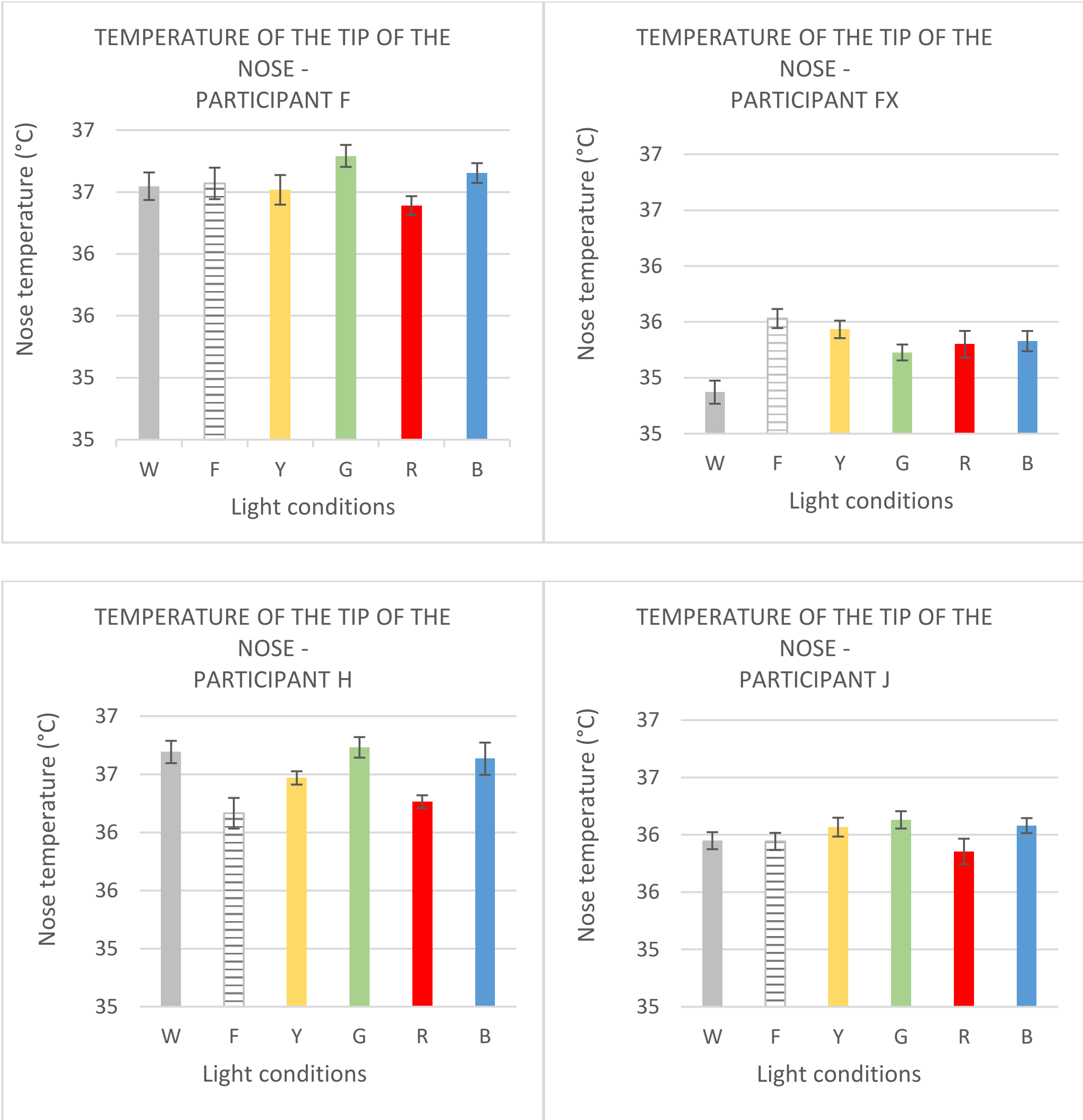


Figure 5. 51. Comparison of the temperature of the tip of the nose under different light conditions obtained for all the participants during the case study.

The sample was very small, so any results obtained in this case study can only be considered as preliminary results.

As seen with the EDA results, many similarities were found between three out of four participants; unexpectedly, the same participants that showed similarities in the temperature analysis. The combination of both physiological signals can help to elucidate the meaning of increased or decreased arousal, as the temperature of the tip of the nose can show the positive and negative valence of the emotion. Consequently, the combination of the EDA information with the temperature of the tip of the nose might be very instructive to understand if these similarities are, in fact, similar as well in meaning or they are only similar partially.

5.4. Behaviour analysis – repetitive behaviour and tics

Tics disorders (TDs), such as Tourette Syndrome (TS) which affects between one and 10 in 1000 children according to the National Institutes of Health (Hirschtritt et al., 2017), are neurobehavioural disorders that start in childhood or adolescence. The first feature of a tic disorder is the presence of chronic motor and phonic tics. Tics are involuntary, abrupt, rapid, repetitive movements (motor) and sounds (phonic). They have different levels and frequency and happen suddenly, with no apparent reason. Tics typically appear in combination with other tics. When they appear in isolation, they are simple tics characterised by rapid movements that involve a single muscle or group of muscles. Simple motor tics include eye blinking, arm jerks, shoulder shrugs and mouth opening, among others. Complex motor tics involve several simple motor tics coordinated in sequences. There are variations of complex motor tics like copropraxia (touching the genital area) and echopraxia (imitating others behaviour). Phonic tics can be simple and complex, as well. A simple phonic tic is a sound or noise such as grunts, sniffs and moans, among others. Complex phonic tics, on the other hand, are repetitions of words and phrases or alterations of volume, slurring sentences, or emphasising specific words. Complex phonic tics include conditions like echolalia (vocal repetition from others), palilalia (repetition of one's own words and sentences), and coprolalia (socially unacceptable language).

Even though the fundamental mechanism of the brain regarding a tic is unclear, it is known that tics disorders are aggravated by anxiety, stress, anger, fatigue or excitement; and reduced during sleep, doing high concentration tasks, being distracted and in emotionally pleased situations (Harris & Singer, 2006). Depending on the nature and level of the tics, sometimes they can make "normal" life difficult.

Tics disorders are typically found in people with attention deficit hyperactivity disorder (ADHD), obsessive-compulsive disorder (OCD), people who suffer from anxiety and depression and children in the autistic spectrum (ASD), among others.

Burd et al. (1987) found that 20% of patients with autism suffer from Tourette Syndrome Disorder. However, other studies show that tics disorders affect around 22% of patients with ASD, in which 11% are affected by Tourette syndrome in particular. There could exist a positive association between the severity of the tics and repetitive behaviour; and the degree of cognitive impairment (Canitano, 2006).

As mentioned before, tics can be a response to extreme and stressful and unpleasant situations, environments or inner feelings. As tics are socially not well accepted, some individuals try to minimise them. Even though a prolonged suppression of tics will not mitigate the unpleasant feeling that can only be mitigated with a tic, this ability to suppress tics will not alter the data collected, as the participants who participated in the experiment cannot control their tics. For this reason, it is assumed that the lack of tics means the participant is experiencing a pleasant feeling.

There is no cure for tics disorder, but they can be minimised with therapy and other treatments. Since the environment can trigger stressful situations and stress is associated with an increase in tics, there is a hope that specific environments might also contribute to a reduction of them.

Given that tics are a common feature of children with autism, and that all four participants in this research suffer from tics disorders, it was expected that the rate per minute (RPM) of tics might shed light on the influence that the different type of lights could have in each participant's level of anxiety and/or behaviour. The interpretation of tics was determined after discussion with the experts such as the carers and therapists who work with the children every day, as they know and understand each of the children and their various characteristics, including the nature of any tics, in each case. In their view the tics are due to increasing levels of anxiety or excitement. Tics were all measured as occurrences because there was no accurate method available, according to the therapists, to interpret whether a tic responded to different internal levels of agitation. Therefore, it was considered, in agreement with the therapists, that the more tics the participant displayed, the more intense could be considered the situation that provoked the repetitive behaviour. For this reason, the tics were measured as if all of them had the same intensity. Every tic was measured in a situation of change (different light conditions). So every tic could be due to the different light condition. The study was looking for differences in the number of tics under different conditions. There is no suggestion of any statistical analysis of the tic rate or number of tics, just a record of how many there were under each condition.

Each participant who participated in the experiment experienced tic disorders, but these are different in each case. All the possible tics, motor and phonic, were identified in the video recordings of the sessions using the software THE OBSERVER TX 14. The RPM of tics was calculated concerning each type and colour of light.

5.4.1. Participant F:

Participant F is diagnosed with Tourette Syndrome. This tic disorder influences her behaviour massively. Sometimes her tics are minimal, but others are massive. Participant F experiences a considerable number of the motor and phonic tics, and these occurred during the experiments. Observed and identified motor tics included head and arm jerks, shoulder shrugs, mouth opening, licking and bringing objects to the mouth, covering objects with her clothes, swinging movements, turning the neck to one side, abdominal contractions, touching objects, copropraxia, kicking, blanks, touching and spinning objects, rolling the tongue and moving the fingers. She always combined these mentioned motor tics in different and complex sequences. Her phonic tics included screaming, grunts, echolalia and other kinds of noises. Therapists have noticed that the participant says a specific sentence with no apparent meaning ("What is the story about Valdemory?") every time she feels hugely anxious. This fact illustrates that the meaning of things that she can say does not necessarily correspond to the real meaning of the words.

Analysis per day:

Influence of the colour of the light in the RPM of tics by day

All the data about the RPM of tics for Participant F can be found in Appendix H and show the RPM of tics obtained in every single session of the experiment for every light exposure for Participant F. Results show that every light exposure presented a different RPM of tics. This finding indicates that the colour and source of the light could have an impact on the level of tics of Participant F.

Patterns observed across the days and consistency of the results

Results show neither any specific pattern nor any trend-line of the RPM of tics, by day. However, the data suggest that the change of the colour and source of the light could have an impact on the level of tics of the participant. Most of the results seem to be consistent. For example, Red and Yellow were set together on days 8, 9 and 10 (Figure 5.52). Results show that on these three days, Participant F had more tics per minute under Red than Yellow, no matter in which order the lights were set.

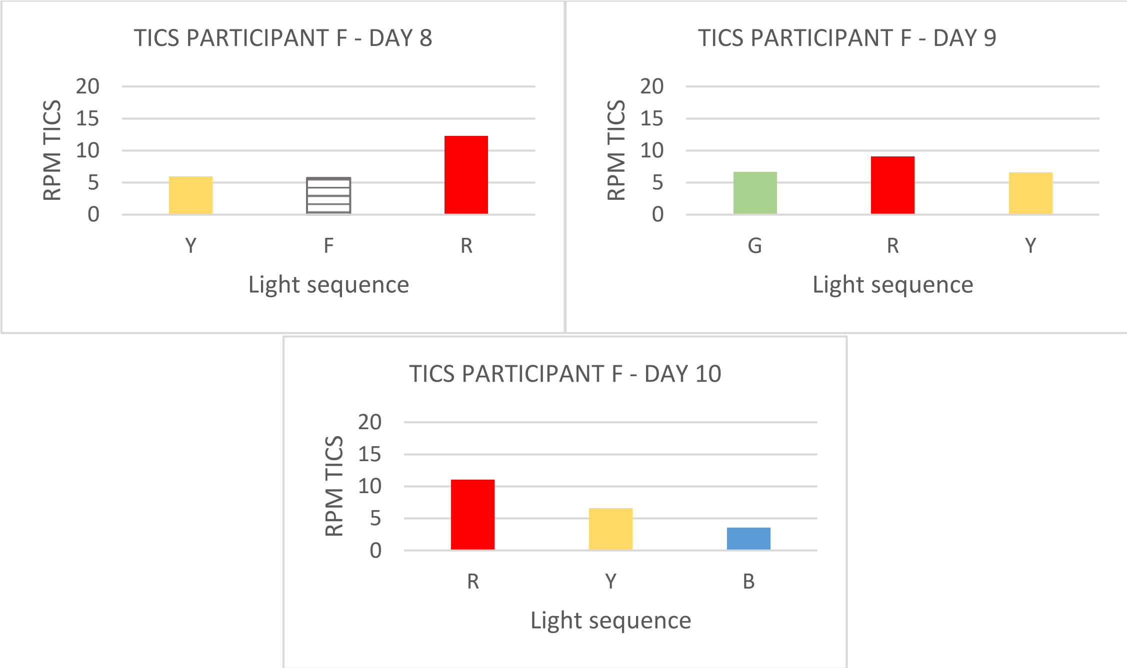


Figure 5. 52. Average RPM of motor and phonic tics combined for Participant F under Red (R) and Yellow (Y), among other lights such as Fluorescent (F) *and* Blue (B), *obtained on days 8, 9 and 10.*

However, some inconsistencies were found when comparing Fluorescent light and Red. Both lights were set together on days 4, 5 and 8 (Figure 5.53). Results show that Participant F had more tics under Fluorescent light compared to Red on days 4 and 5. However, on day 8, the participant had more tics under Red compared to Fluorescent light. These findings indicate that results might be consistent, but more sequences and light exposures should be done.

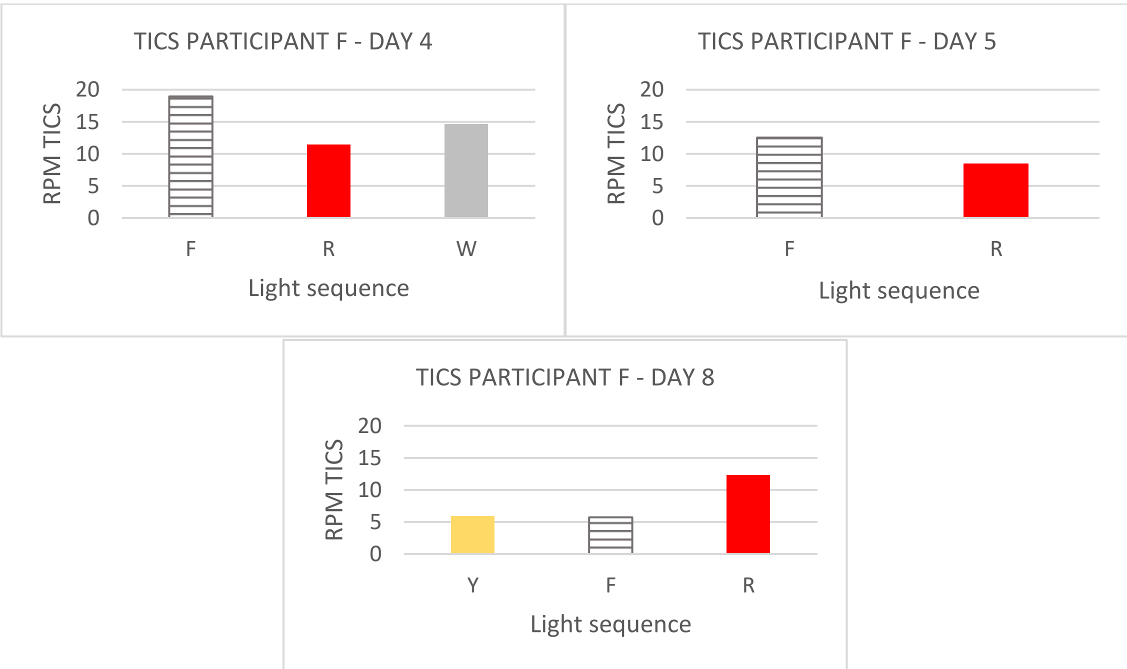


Figure 5. 53. Average RPM of motor and phonic tics combined for Participant F under Fluorescent light (F) and Red (R), among other lights such as White (W) and Yellow (Y), obtained on days 4, 5 and 8.

Influence of the source of the light in the RPM of tics: Fluorescent light vs White LED

Figure 5.54 shows contradictory results from day 4 and days 11 and 12. On day 4, Participant F had more tics per minute under Fluorescent light than under White light. However, on days 11 and 12, Participant F had more tics under White than under Fluorescent light. However, results show that there is a difference in the RPM of tics when both lights are set on the same day. This finding indicates that the source could have an impact on the RPM of tics of Participant F, although it might not always be consistent.

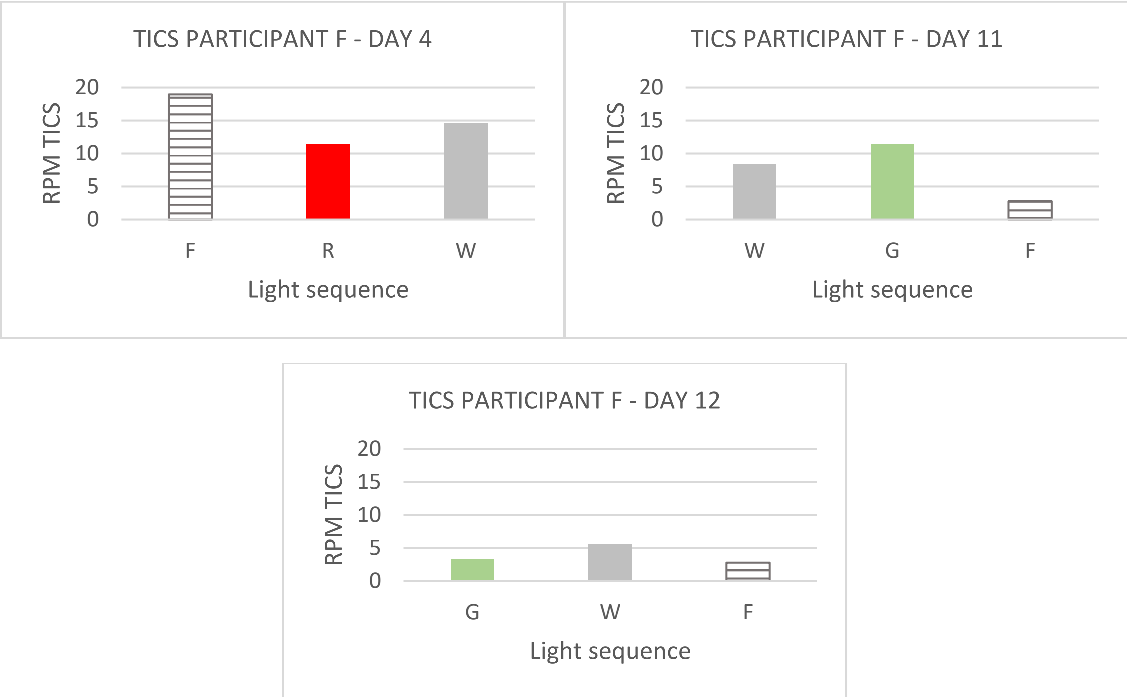


Figure 5. 54. Average RPM of motor and phonic tics combined for Participant F under White (W) and Fluorescent light (F), among other lights such as Green (G) and Red (R), obtained on days 4, 11 and 12.

Comparison between motor and phonic tics under different light conditions

Figure 5.55 compares the Average RPM of motor and phonic tics under different light conditions obtained for Participant F during the case study. This figure is quite revealing in many ways. First, the participant experienced a different RPM of tics (motor and phonic) depending on the lights used (W=3.28,6.11; F=7.57,3.6; Y=3.67,3.37; G=3.54,3.1; R=4.95,4.85; B=4.51,4.35). The rate per minute of motor tics remained constant under White, Yellow and Green, but it increased when Blue, Red and Fluorescent light is on. Rate per minute of phonic tics, however, remained constant under Fluorescent light, Yellow and Green, and increased under White, Red and Blue lights. Secondly, the results show consistency on the relationship between motor and phonic tics from the coloured LED lights, observing a modest bigger amount of motor tics per minute than phonic tics (Y=3.67 > 3.37; G=3.54 > 3.1; R=4.95 > 4.85; B=4.51 > 4.35).

Nevertheless, this consistency did not apply for White LED and Fluorescent light. On the one hand, even though under Fluorescent light the prevalence of motor tics over phonic tics was evident as it happened under the coloured LED lights, there was a considerable difference between motor and phonic tics (F=7.57,3.6). The average RPM of motor tics was 2.1 times the RPM of phonic tics. On the other hand, under White conditions, there was an unusual and high prevalence of phonic tics over motor tics (W=3.28,6.11). The average RPM of motor tics was 0.54 times the RPM of phonic tics.

Taken together, these findings indicate that the colour of the light and the source of lighting could have a substantial impact on the RPM of tics and, for instance, the behaviour and mood of the participant. For example, the participant shows a higher amount of tics under Fluorescent light (F=7.57,3.6) compared to Yellow (Y=3.67,3.37), and Green (G=3.54,3.1). These results can encourage therapists to use Yellow, and Green LED lights over Fluorescent light to reduce the likelihood of tic disorder symptoms.

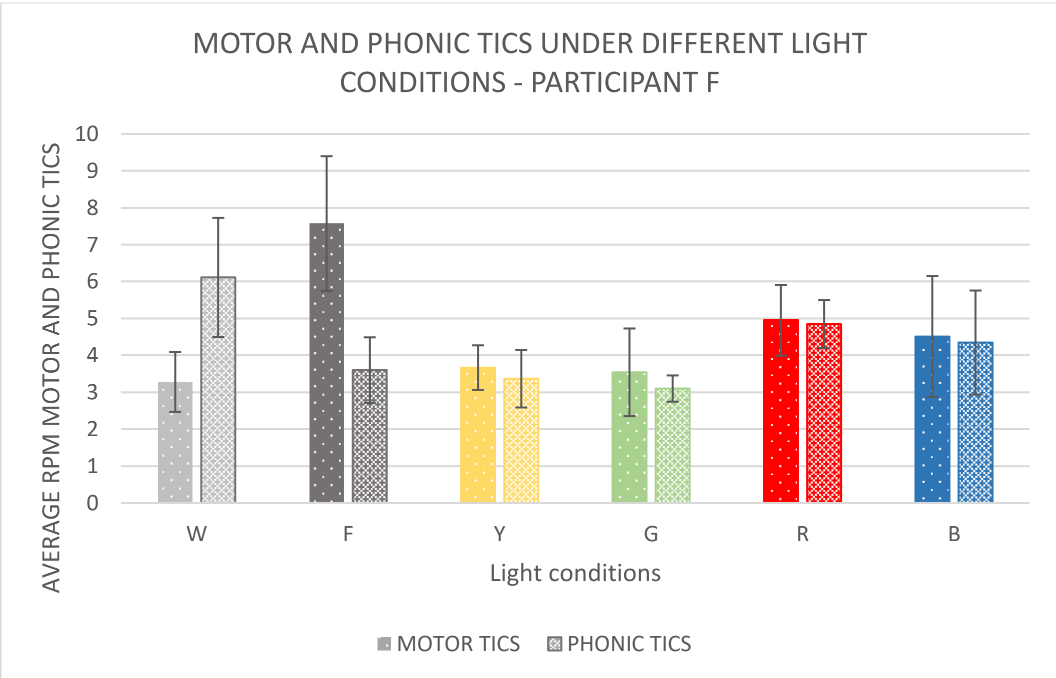


Figure 5. 55. Comparison of the Average RPM of motor and phonic tics under different light conditions obtained for Participant F during the case study.

Influence of the colour of the light in behaviour and tics

Figure 5.56 displays the total average of RPM of both motor and phonic tics combined, as they are considered equally important for the carers of the participants. The results show that the participant experienced more tics per minute under Fluorescent light (F=11.16, Range 2.8-19 tics per minute) compared to any LED lights. This finding indicates that the source of the light could have an impact on the behaviour of the participant. It can thus be suggested that Fluorescent light should not be used as it seems it could increase anxiety levels, and it can be suggested to use LED lights instead.

Focusing the attention on the LED lights, during White and Red lights the participant showed the highest RPM of tics (W=9.38, Range 3.5-14.6 tics per minute; and R=9.77, Range 6.3-12,3 tics per minute) while during the Green, the participant had the lowest RPM of tics (G=6.64, Range 3.24-11.5 tics per minute) followed by Yellow (Y=7.05, Range 5.9-8.8 tics per minute). There can be recommended to use Green and Yellow LED lights, preferably, to encourage relaxation or/and concentration and experience a reduction of tics.

Influence of the source of the light in the behaviour and tics: Fluorescent light vs White LED

As mentioned before, Participant F experienced more tics under Fluorescent light (F=11.16, Range 2.8-19 tics per minute) than under any other light. That fact evidences that the different sources of light could influence the RPM of tics differently.

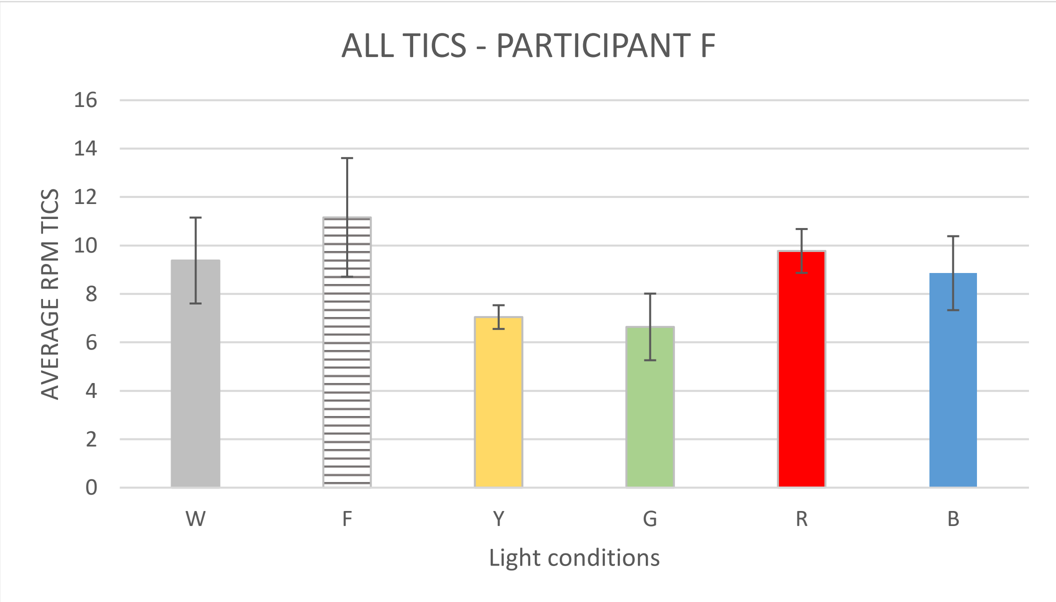


Figure 5. 56. Average RPM of motor and phonic tics combined under different light conditions obtained for Participant F during the case study.

5.4.2. Participant FX:

Participant FX has a chronic tic disorder, and he experiences both motor and phonic tics. The motor tics observed were arm jerks, cover his mouth, repetitive behaviour, eye-rolling and blinking, shoulder twitching, motor block, touching and stretching his fingers and hear jerks, and rarely it was observed copropraxia. In terms of phonic tics, the language of Participant FX is echolalic. As he repeats what he hears or things he heard previously, his level of understanding and language is masked by his ability to speak. He is not able to follow a conversation. In addition to echolalia, Participant FX emitted noises, he screamed, and there were observed alterations of volume and intensity and slurrings. Even though the language of Participant FX is echolalic, sometimes he repeats what he hears as a confirmation or response to a question. In these cases, echolalia behaviour will not be considered as a tic, as it is not abrupt, involuntary and spontaneous. However, when he repeats words or sentences, he heard without any context or/and repeatedly, it is considered a tic.

Analysis per day:

Influence of the colour of the light in the RPM of tics by day

All the data about the RPM of tics for Participant FX can be found in Appendix H and show the RPM of tics obtained in every single session of the experiment for every light exposure for Participant FX. Results show that every light exposure presented a different RPM of tics. This finding indicates that the colour and source of the light could have an impact on the level of tics of Participant FX.

Patterns observed across the days and consistency of the results

Results do not show any specific pattern or trend-line of the RPM of tics by day. This finding indicates too that the change of the colour and source of the light could have an impact on the level of tics of the participant. Most of the results seem to be consistent.

For example, Red and Yellow were set together on days 5, 8, 9 and 10 (Figure 5.57). Results show that on days 5, 9 and 10, Participant FX had more tics per minute under Red than Yellow, no matter the order the lights were set. However, inconsistencies were found on day 8, in which he had higher RPM of tics under Yellow than under Red light.

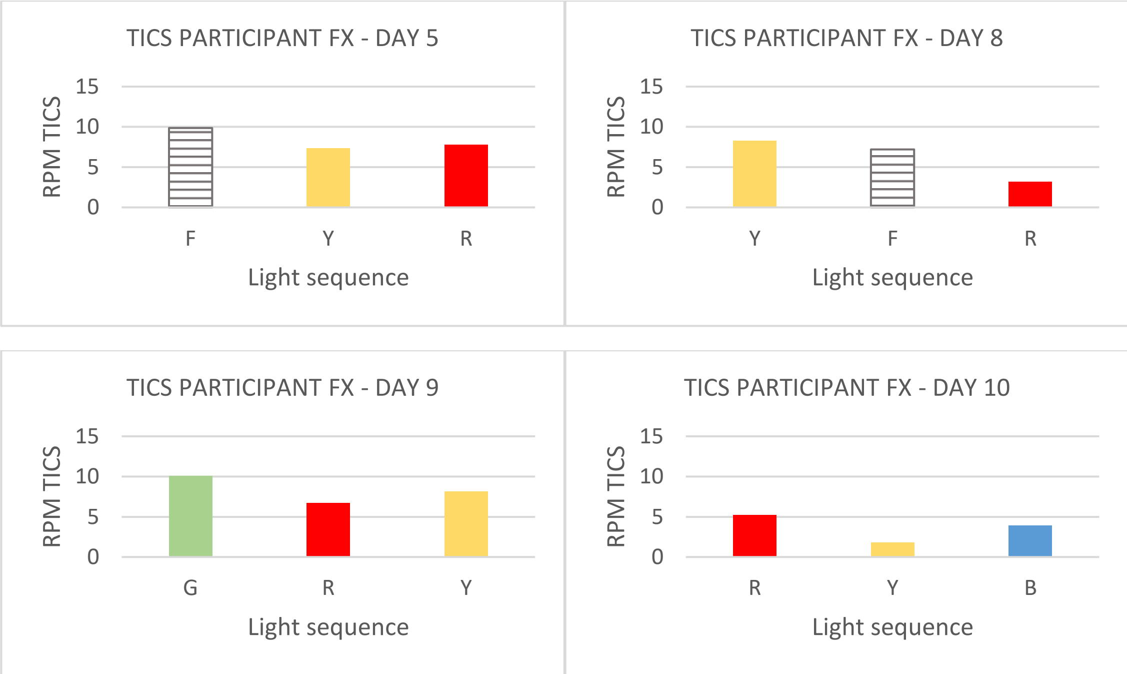


Figure 5. 57. Average RPM of motor and phonic tics combined for Participant FX under Red (R) and Yellow (Y), among other lights such as Fluorescent (F), Green (G) and Blue (B) obtained on days 5, 8, 9 and 10.

Some inconsistencies were also found when comparing Green and Blue light (Figure 5.58). Participant FX had more tics under Blue compared to Green on days 6 and 7. However, on day 14, the participant had more tics under Green light. These findings indicate that results might be consistent but that more sequences and light exposures should be done.

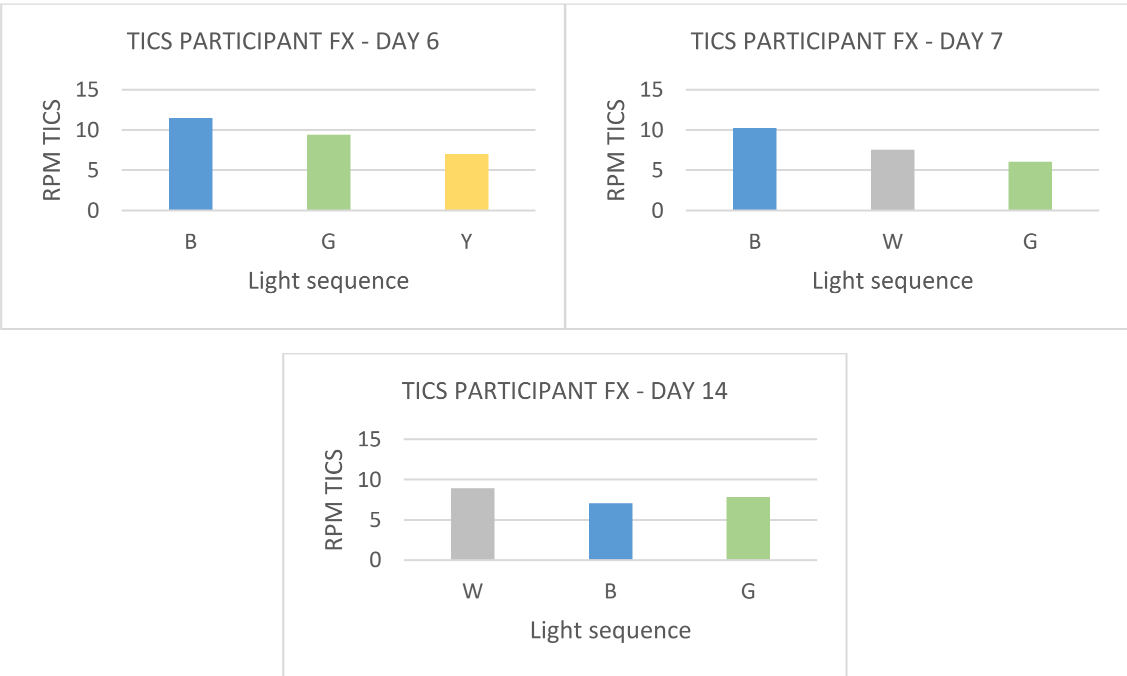


Figure 5. 58. Average RPM of motor and phonic tics combined for Participant FX under Blue (B) and Green (G), among other lights such as White (W) and Yellow (Y), obtained on days 6, 7 and 14.

Influence of the source of the light in the RPM of tics: Fluorescent light vs White LED

Both lights were set together on days 4, 11 and 12 (Figure 5.59), although the lights were set in a different order. Results indicate that on day 4, Participant FX had more tics per minute under Fluorescent light compared to White light. However, on days 11 and 12, more tics per minutes were observed under White than under Fluorescent light. This finding indicates that the source could have an impact on the RPM of tics of Participant FX and that White light might induce more tics per minute than Fluorescent light, However, the inconsistencies observed on day 4 suggest that further research should be done.

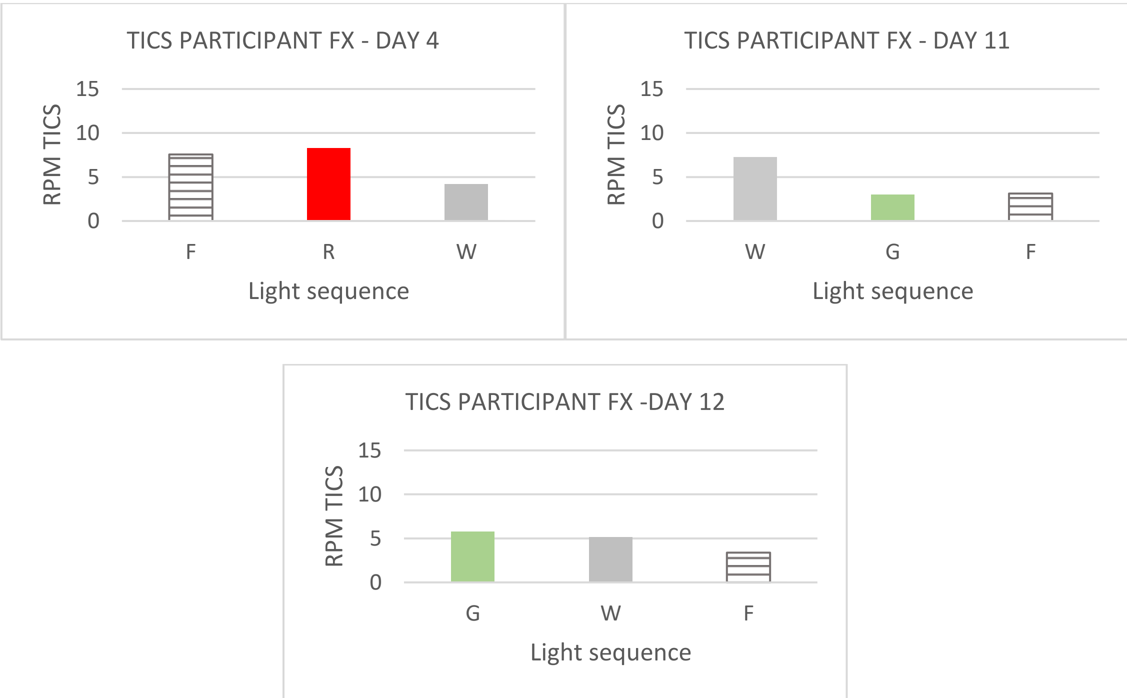


Figure 5. 59. Average RPM of motor and phonic tics combined for Participant FX under White (W) and Fluorescent light (F), among other lights such as Red (R) and Green (G), obtained on days 4, 11 and 12.

Comparison between motor and phonic tics under different light conditions

Figure 5.60 compares the average RPM of motor and phonic tics under different light conditions obtained for Participant FX during the case study. This figure is quite revealing in several ways. First, the rate per minute of motor tics remained relatively constant over the four coloured LED lights with values which differ from less than a half tic per minute (W=3.95,3.05; F=2.13,4.28; Y=2.50,4.00; G=2.59,4.45; R=2.69,3.67; B=3.09,5.31). However, during White, the RPM of motor tics was higher than any other light (3.95), and the RPM of motor tics during Fluorescent light was lower than any other light. The results also show that the RPM of phonic tics varied more than the motor tics. The rate per minute of phonic tics was around one tic per minute more than the motor tics except under White, in which the phonic tics measure was one tic per minute lower than the motor tics. These findings indicate that the colour of the light could have a substantial impact on the rate per minute of phonic tics, but that the impact of motor tics is not significant. Nevertheless, the relationship between motor and phonic tics was consistent in all the light conditions except for White light. Under White conditions, there was an unusual and high prevalence of motor tics over phonic tics (W=3.95,3.05).

On the other hand, Figure 5.60 also shows the different reactions Participant FX had under White LED and Fluorescent light (W=3.95,3.05; F=2.13,4.28) even though the hue and intensity of both lights are the same. This finding indicates that the source of the light could have an impact on the rate per minute of both phonic and motor tics when comparing two lights with the same hue and intensity.

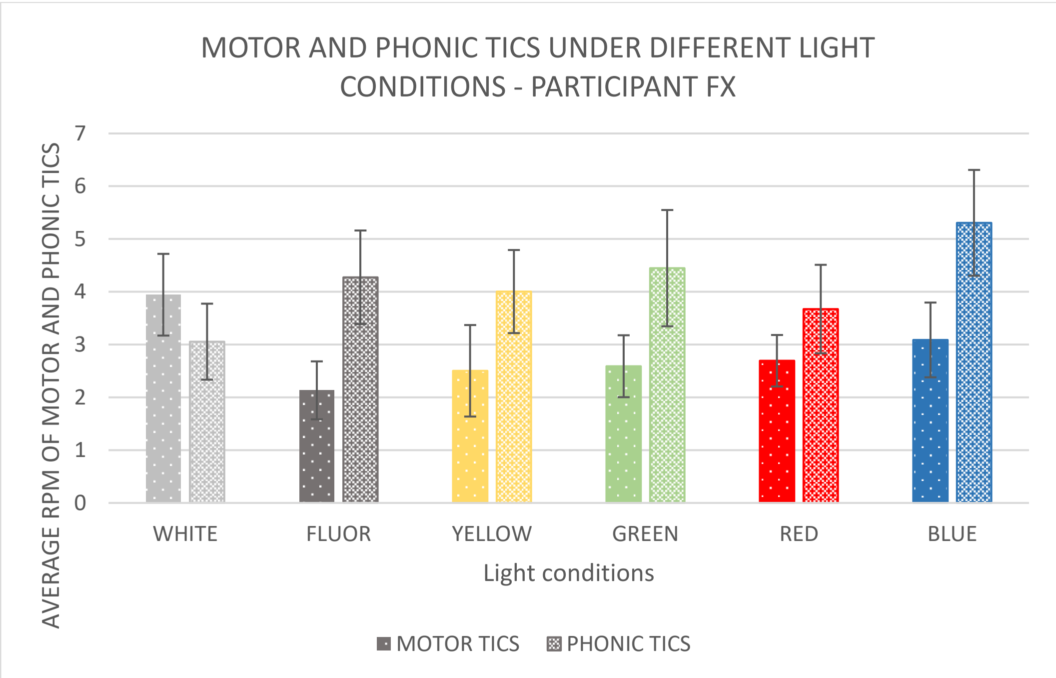


Figure 5. 60. Comparison of the Average RPM of motor and phonic tics under different light conditions obtained for Participant FX during the case study.

Influence of the colour of the light in behaviour and tics

Figure 5.61 displays the total average of RPM of both motor and phonic tics combined, as they are considered equally important for the carers of the school. The results show that the participant experienced more tics per minute under Blue (B=7.57, Range 3.9-11.44 tics per minute) compared to any other light. During Fluorescent light and Red, the participant had the lowest values of RPM of tics (F=6.38, Range 3.12-9.86 tics per minute; and R=6.36, Range 2.96-10.08 tics per minute). Figure 5.58 also shows the comparison of tics between White LED and Fluorescent light. Even though the White could have induced more tics than the Fluorescent light (W=7.0, Range 4.2-8.96 tics per minute; F=6.38, Range 3.12-9.86 tics per minute), the difference might not be significant since it is less than a tic per minute. These findings indicate that the source of the light could not have as significant an impact on the behaviour of the participant as does the colour of the light. It could thus be suggested that Blue should not be used as it seems it could increase anxiety levels for this participant and that it might be better to use Red s or Fluorescent light instead to encourage relaxation or/and concentration and a reduction of tics.

Influence of the source of the light in the behaviour and tics: Fluorescent light vs LED

Participant FX experienced more tics under White (W=7.0, Range 4.2-8.96 tics per minute) than under Fluorescent light (F=6.38, Range 3.12-9.86 tics per minute). However, the difference between White and Fluorescent light is less than tic per minute. These results indicate that the light source could not influence the RPM of tics.

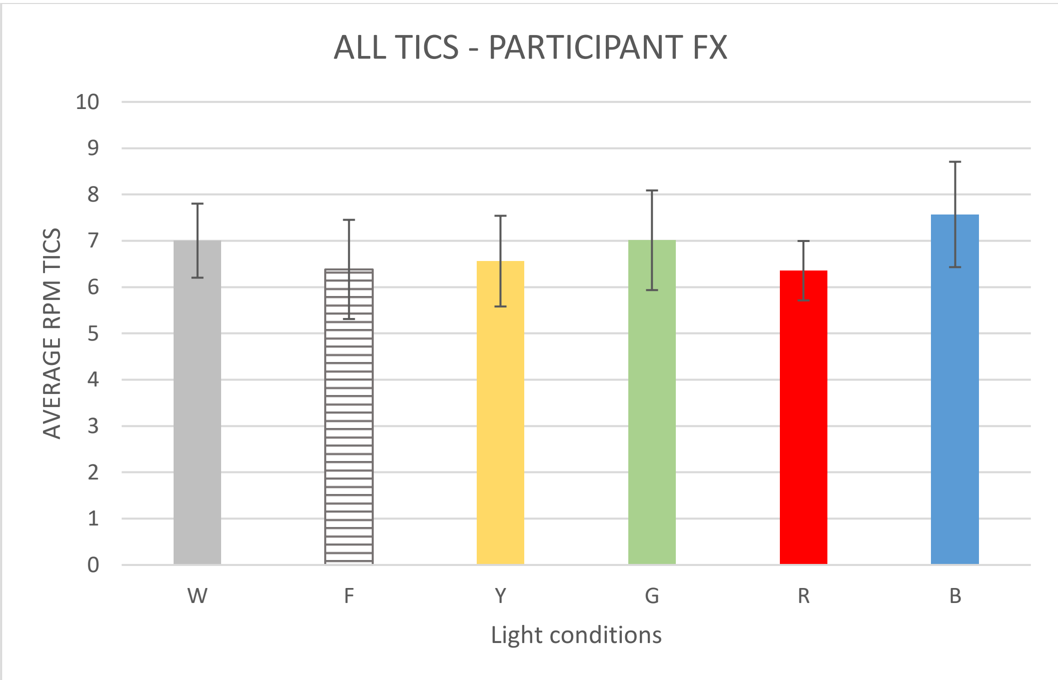


Figure 5. 61. Comparison of the Average RPM of motor and phonic tics combined under different light conditions obtained for Participant FX during the case study.

5.4.3. Participant H:

Participant H has a chronic motor tic disorder. His motor tics include biting his tongue, aggressive behaviour against himself, and the property; scratch his head, arm jerks, head jerking and shoulder shrugs.

Analysis per day:

Influence of the colour of the light in the RPM of tics by day

All the data about the RPM of tics for Participant H can be found in Appendix H and show the RPM of tics obtained every single session of the experiment for every light exposure for Participant H. Results show that every light exposure presented a different RPM of tics. This finding indicates that the colour and source of the light could have an impact on the level of tics of Participant H.

Patterns observed across the days and consistency of the results

Results do not show any specific pattern or trend-line of the RPM of tics by day. This finding indicates too that the change of the colour and source of the light could have an impact on the level of tics of the participant. Even though the sample is too small, most of the results seem to be consistent. For example, Red and Yellow were set together on days 3, 5, 8 and 10 (Figure 5.62). Results show that Participant H had more tics per minute under Yellow than under Red, no matter what order of lights was set.

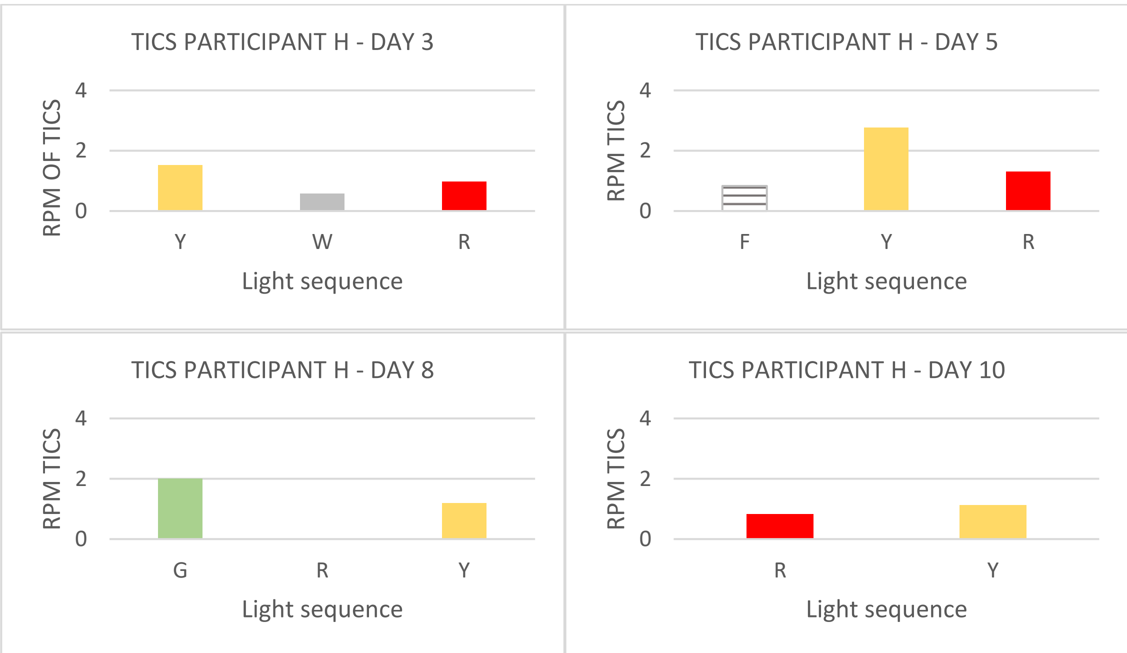


Figure 5. 62. Average RPM of motor tics for Participant H under Red (R) and Yellow (Y), among other lights such as Fluorescent (F), White (W) and Green (G), obtained on days 3, 5, 8 and 10.

On days 3 and 4, Red and White were set, and Participant H had more tics under Red both days, showing consistent results (Figure 5.63).

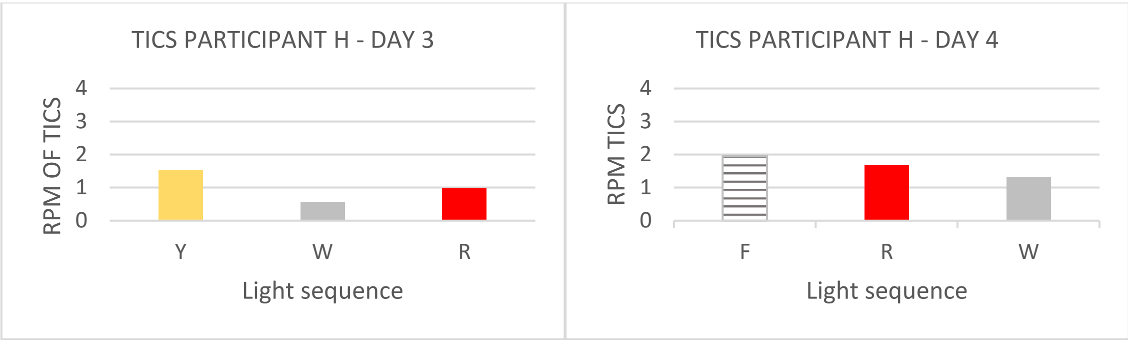


Figure 5. 63. Average RPM of motor tics for Participant H under Red (R) and White (W), among other lights such as Fluorescent light (F) and Yellow (Y), obtained on days 3 and 4.

However, some inconsistencies were found on day 6, 7 and 14 (Figure 5.64). While on days 6 and 14, Participant H had more tics per minute under Green compared to Blue, on day 7, he had more tics under Blue light. These findings indicate that results might be consistent but that more sequences and light exposures should be done.

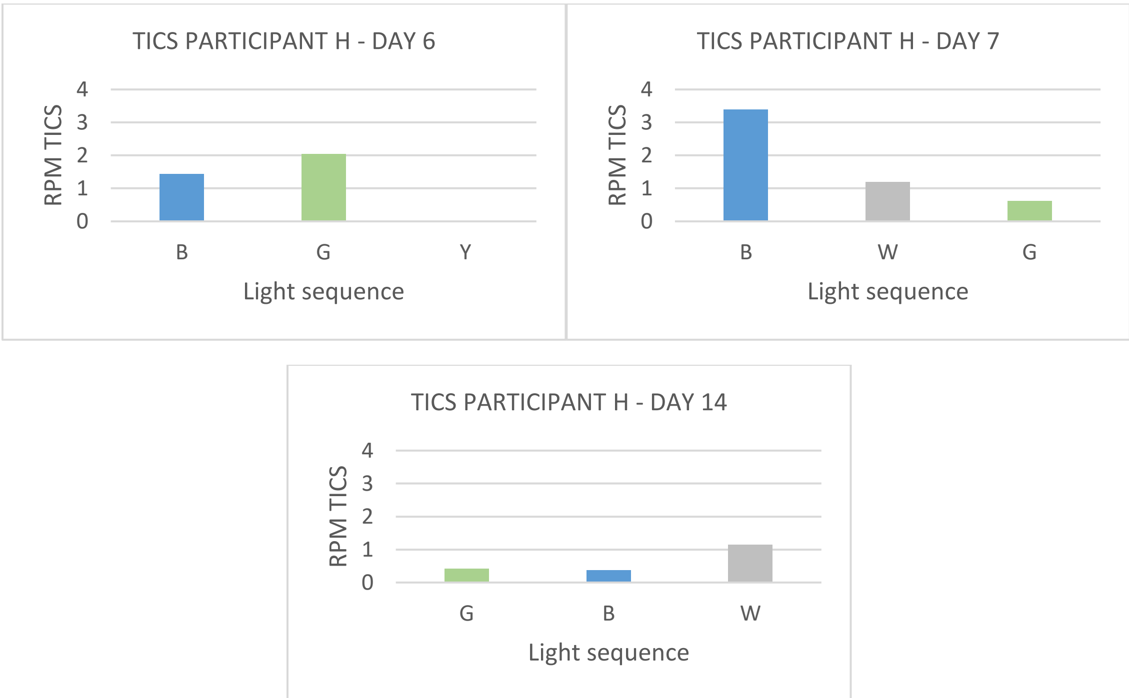


Figure 5. 64. Average RPM of motor tics for Participant H under Green (G and, Blue (B), among other lights such as Yellow (Y) and White (W), obtained on days 6, 7 and 14.

Influence of the source of the light in the RPM of tics: Fluorescent light vs White LED

Both lights were set together only on day 4 (Figure 5.65); therefore, the results can be anecdotic. On day 4, Participant H had more tics per minute under Fluorescent light compared to White light. However, the difference is insignificant, less than one tic per minute. This finding is not enough to indicate whether the source could have an impact on the RPM of tics of Participant H.

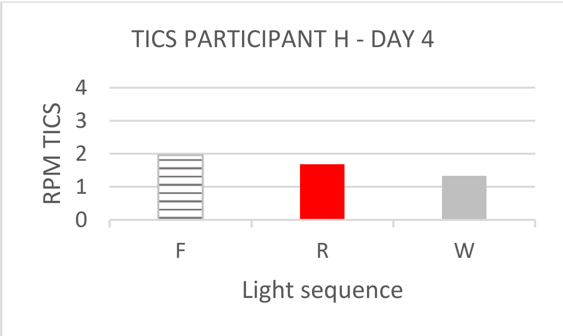


Figure 5. 65. Average RPM of motor tics for Participant H under Fluorescent light (F), Red (R) and White (W) obtained on day 4.

Influence of the colour of the light on behaviour and tics

Figure 5.66 displays the average of RPM of motor tics under different light conditions obtained for Participant H during the case study. Participant H was not able to attend the sessions regularly, so it was possible to collect only a small sample of data from this participant. For instance, the analysis of the motor tics might be merely anecdotic. The results show that the participant suffered the highest values of tics per minute under Yellow (Y=1.48, Range 0-2.77 tics per minute) followed closely by Fluorescent light (F=1.39, Range 0.83-1.96 tics per minute) compared to any other light. During the White, the participant had the lowest average of RPM of tics (W=0.88, Range 0.42-1.33 tics per minute). Even though the Fluorescent light seemed to induce more tics than the White (W=0.88; F=1.39), the difference could not be practically significant since it is half a tic per minute. However, bearing in mind that results shown were collected from an especially small sample, these findings could indicate that the colour of the light and the source of the light could not have an impact on the tic behaviour of Participant H as the difference of RPM of tics is just 0.6 tic per minute. However, if we consider the behavioural tendencies which appear in Figure 5.63, it could be suggested that Yellow and Fluorescent light should not be used with this participant as it seems they could increase anxiety levels, and it could be suggested that other LED lights be used instead of such as White or Green lights.

Influence of the source of the light on the behaviour and tics: Fluorescent light vs LED

Participant H experienced more tics under White (W=0.88, Range 0.42-1.33 tics per minute) than under Fluorescent light (F=1.39, Range 0.83-1.96 tics per minute). However, the RPM of tics Participant FX had under Fluorescent light was similar to the RPM obtained under Red (R=1.19, Range 0.83-1.68 tics per minute). The fact that these two different lights and sources have similar RPM of tics and that the difference between White and Fluorescent light was less than a tic per minute suggests that the source of the light might not be particularly influential on the RPM of tics.

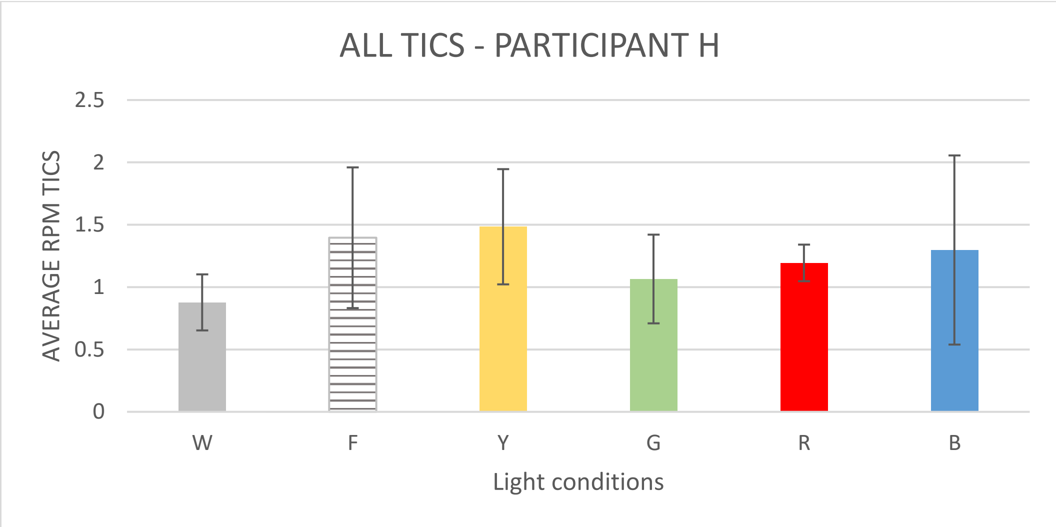


Figure 5. 66. Comparison of the Average RPM of motor tics under different light conditions obtained for Participant H during the case study.

5.4.4. Participant J:

As already mentioned in the previous sections, the sessions of Participant J suffered alterations compared to the other participants because the participant wanted to change the colour of the light often. On the one hand, as Participant J sometimes asked for a change in the colour of the light, he experienced light exposures of less than 30 seconds, symbolised with the symbol (*) which might not show alterations in behavioural responses; therefore, these values might not be comparable to the ones obtained during longer exposures (Caldwell & Jones, 1984). Nevertheless, even though these exposures cannot be compared to the longer exposures, they will also be shown in this chapter for future discussion.

On the other hand, Participant J also asked for darker versions of the colour blue. The new tone was obtained by changing only the hue of the light, maintaining the saturation and the intensity, as it happened with the rest of the light exposures. As seen in Chapter Two, different values of the properties of the colour, such as hue can influence the individual differently (Wilms & Oberfeld, 2016). Consequently, even though the exposures with new different hues, symbolised with the symbol (+) will be considered as “Blue” for easier comprehension, the changes will be noted so any alterations in the results could be considered and discussed in the future.

Participant J has chronic vocal tic disorder and, less common; he also experienced chronic motor tics. The motor tics that Participant J presented included arm and head jerks, shoulders shrugs, aggressive behaviour against himself, other people, and the property; and scratching his head or nose. In terms of phonic tics, Participant J has echolalia and emits noises, screaming, alteration of volume and intensity, and slurring. Sometimes, the participant spent a few minutes of emitting noises. In terms of specifying the tic data, it is considered that a tic is different every time he changes the intensity, volume or type of noise.

Analysis per day:

Influence of the colour of the light in the RPM of tics by day

All the data about the RPM of tics for Participant J can be found in Appendix H and show the RPM of tics obtained every single session of the experiment for every light exposure for Participant J. Results show that every light exposure presented a different RPM of tics. This finding indicates that the colour and source of the light could have an impact on the level of tics for Participant J.

Patterns observed across the days and consistency of the results

Results do not show any specific pattern or trend-line of the RPM of tics by day. This finding indicates too that the change of the colour and source of the light could have an impact on the level of tics of the participant. Most of the results seem to be consistent.

For example, Red and White were set together on days 4, 7, 9 and 13 (Figure 5.67). Results show that Participant J had more tics per minute under White than under Red light, no matter what order in which the lights were set.

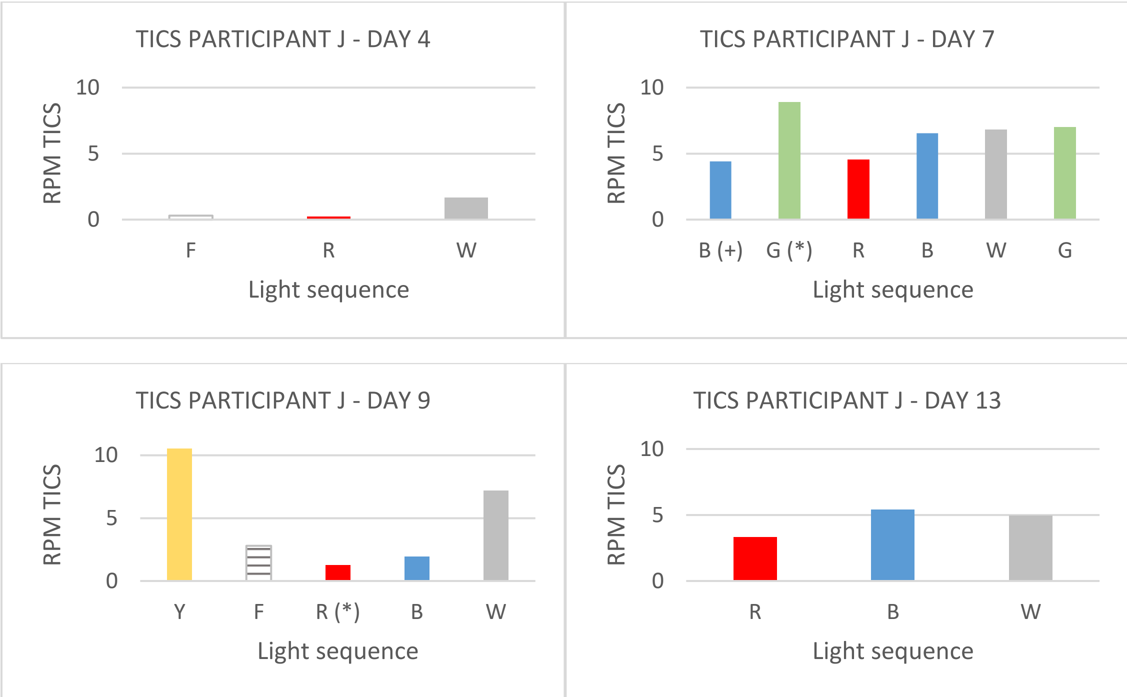


Figure 5. 67. Average RPM of motor and phonic tics combined for Participant J under Red (R) and White (W), among other lights such as Fluorescent (F), Green (G), Yellow (Y) and Blue (B), obtained on days 4, 7, 9 and 13.

Another example of consistency is when comparing the RPM of tics under Green and Blue. Figure 5.68 shows the RPM of tics under both lights, which were set together on six days (Day 6, 7, 8, 10, 11 and 14). Even though they were set in a different order. Five out of six days

Participant J had more tics per minute under Green than under Blue light. The only session when Participant J had more tics under Blue than under Green was on day 14.

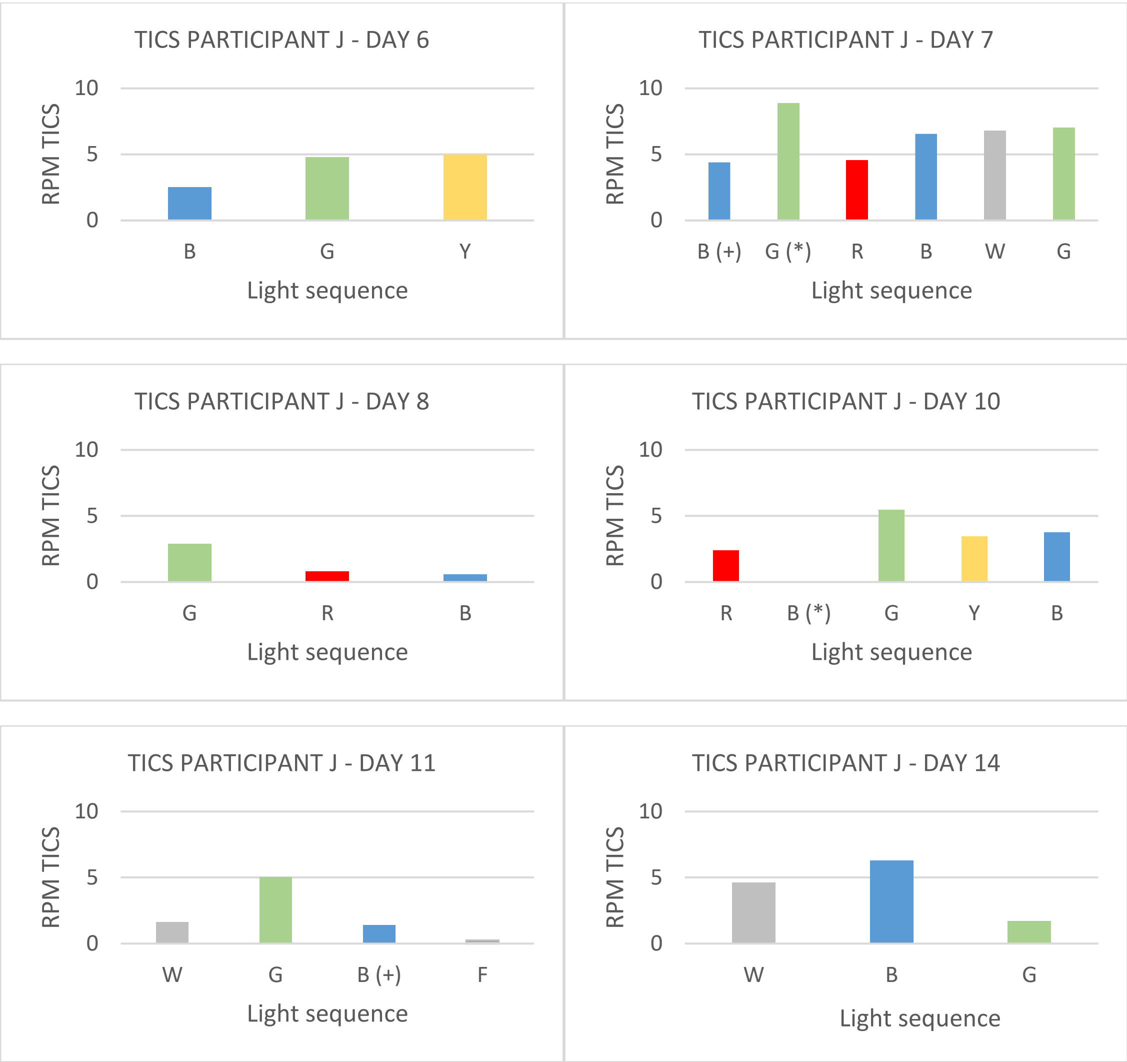


Figure 5. 68. Average RPM of motor and phonic tics combined for Participant J under Blue (B) and Green (G), among other lights such as White (W), Yellow (Y), Red (R) and Fluorescent (F), obtained on days 6, 7, 8, 10, 11 and 14.

These findings indicate that the colour of the light could impact on the RPM of tics and that results on different lights might be consistent, but more sequences and light exposures should be done.

Influence of the source of the light in the RPM of tics: Fluorescent light vs White LED

Both lights were set together on days 4, 9 and 11 (Figure 5.69), although the lights were set in a different order. Results indicate Participant J had more tics per minute under White compared to Fluorescent light on the three days, no matter the order of the lights. This finding indicates that the source could have an impact on the RPM of tics of Participant J, and that White induces more tics than Fluorescent light.

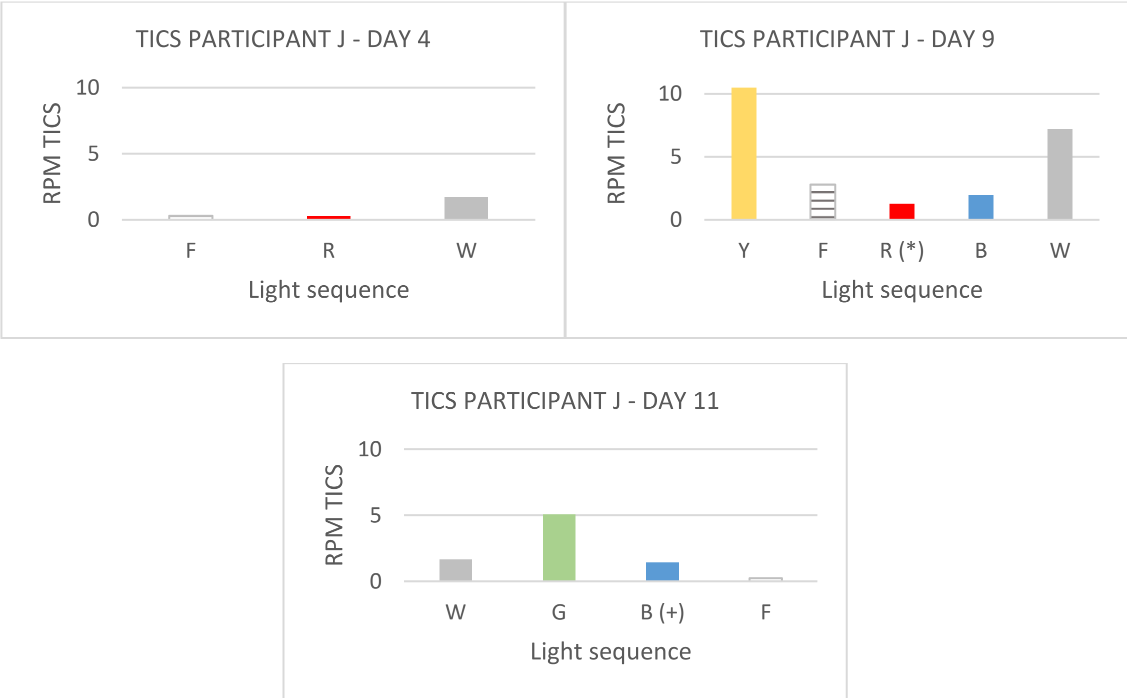


Figure 5. 69. Average RPM of motor and phonic tics combined for Participant J under White (W) and Fluorescent light (F), among other lights such as Red (R), Yellow (Y), Blue (B) and Green (G), obtained on days 4, 9 and 11.

Comparison between motor and phonic tics under different light conditions

Figure 5.70 compares the average RPM of motor and phonic tics under different light conditions obtained for Participant J during the case study. This figure is quite revealing in several ways. First, the participant experienced a different RPM of tics (motor and phonic) depending on the lights used (W=1.97,2.06 F=1.39; F=0.17,0.82; Y=0.54,3.04; G=1.96,3.10; R=0.7,1.29; B=1.67,0.98). The rate per minute of motor tics remained higher under White and Green, but it decreased when Fluorescent light and Yellow were on. Rate per minute of phonic tics, however, was higher under Yellow and Green lights and was lower under Blue LED and Fluorescent light. Secondly, the results show a consistency in the relationship between motor and phonic tics on all the lights except Blue LED, observing a bigger and variable amount of phonic tics per minute than motor tics (W=1.97 < 2.06; F=0.17 < 0.82; Y=0.54 < 3.04; G=1.96 <

3.10; R=0.7 < 1.29). However, under the Blue, there was a greater prevalence of motor tics over phonic tics (B=1.67 > 0.98).

Taken together, these findings indicate that the colour of the light and the source of lighting could have an impact on the RPM of tics. For example, the participant shows a more considerable amount of tics under Yellow (Y=0.54, 3.04) and Green s (G=1.96, 3.10) compared to Fluorescent light (F=0.17, 0.82), and Blue (B=1.67, 0.98). These results could encourage therapists to consider using Blue s over Yellow and Green LED for this participant in order to reduce tic disorder symptoms.

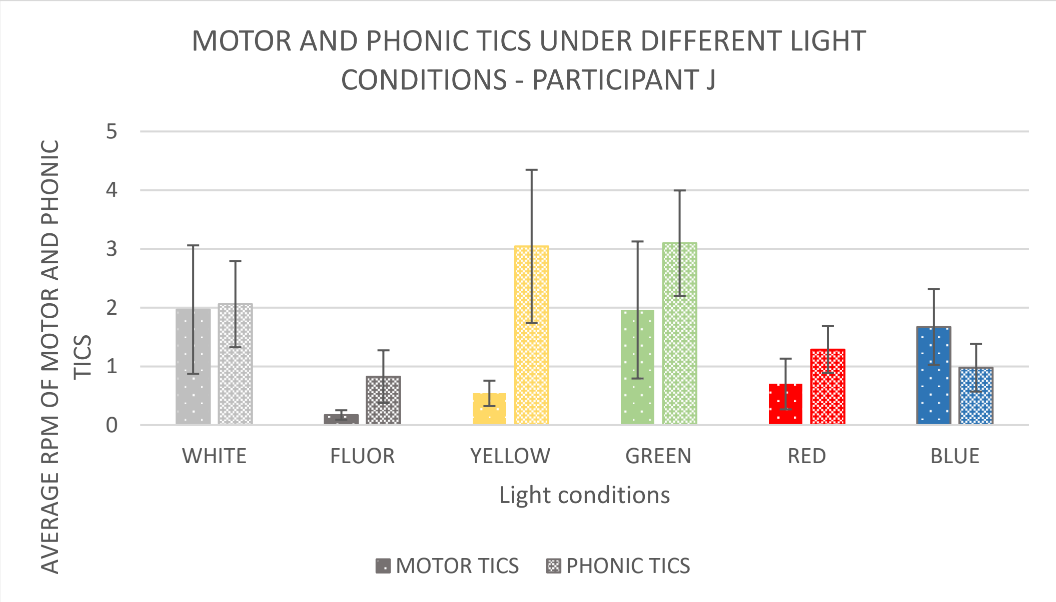


Figure 5. 70. Comparison of the Average RPM of motor and phonic tics under different light conditions obtained for Participant J during the case study.

Influence of the colour of the light in behaviour and tics

Figure 5.71 displays the total average of RPM of both motor and phonic tics combined, as they are considered equally important for the carers of the school. The results show that the participant experienced more tics per minute under Green (G=5.11, Range 1.69-8.89 tics per minute) compared to any other lights. The results show that the participant suffered fewer tics under Fluorescent light (F=1.00, Range 0.22-2.8 tics per minute) than under any other light. This finding indicates that the source and colour of the light could have an impact on the behaviour of the participant. During Red (R=1.97, Range 0-4.55 tics per minute) and Blue (B=2.65, Range 0-6.55 tics per minute) Participant J also experienced lower RPM of tics compared to White (W=4.03, Range 1.25-7.2 tics per minute) and Yellow s (Y=3.58, Range 0-10.8 tics per minute). The difference in RPM of tics on the different light conditions indicates that the colour of the light could also have an impact on the behaviour of the participant. It can thus be suggested that Green (G=5.11, Range 1.69-8.89 tics per minute) should not be used as it seems it could increase anxiety levels, and it can be suggested to use Fluorescent light, Red or Blue LED lights instead.

The interesting fact that Participant J asked many times to perform the tasks under Blue conditions suggests that the level of tics could be attributed to relaxation. In this case, Blue might be recommended to boost happiness and relaxation on the participant.

Influence of the source of the light on the behaviour and tics: Fluorescent light vs White LED

Focusing the attention on comparing White LED and Fluorescent lights, Participant J showed highest values of RPM of tics during the White (W=4.03) while during the Fluorescent light, the participant had the lowest average of RPM of tics (F=1.00). Considering that in both conditions, the hue and the intensity were the same, this finding indicates that the source of the light could have an impact on the behaviour of the participant. It could be recommended to consider using Fluorescent lights instead of White LED to encourage relaxation or/and concentration and experience a reduction of tics, although these results would contradict the hypotheses of the therapists.

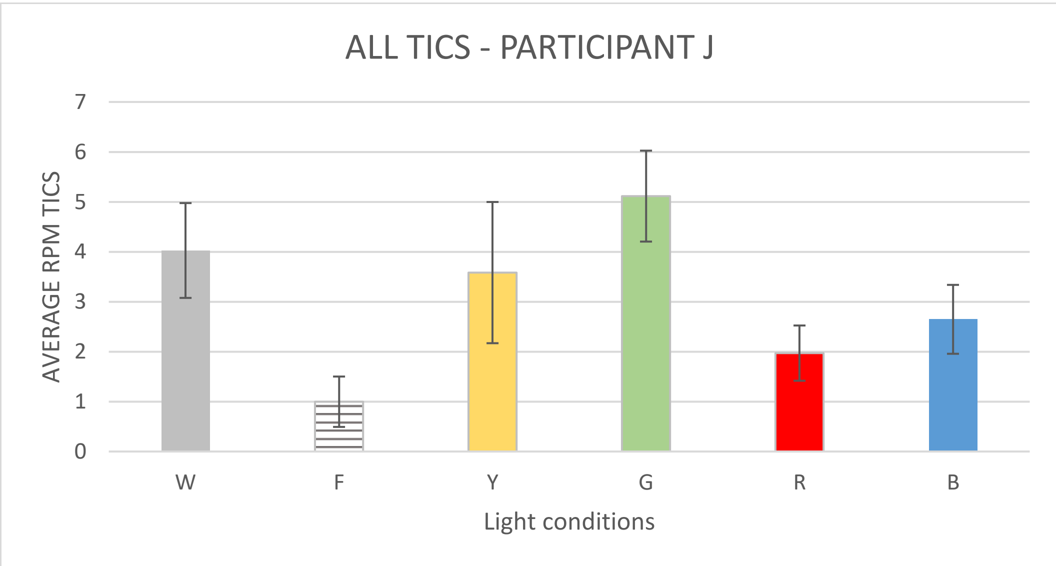


Figure 5. 71. Average RPM of motor and phonic tics combined under different light conditions obtained for Participant J during the case study.

As mentioned before, participant J wanted to change the colour of the light often and even the tone of the light. This attitude resulted in variations of time and hue. As previously seen in the literature, both factors can have a significant influence on the results. For this reason, Figure 5.72 displays the total average of RPM of both motor and phonic tics combined for Participant

J, as they are considered equally important for the carers of the school. Avoiding all the exposures shorter than 30 seconds and the exposures which altered the properties of the light.

The only lights affected by these two variations were the lights Green, Red, and Blue lights. Results on the temperature of the tip of the nose are different depending on the colour of the light. This finding indicates that the colour of the light could have an impact on the temperature of the tip of the nose of the participant.

When omitting the light exposures which lasted less than 30 seconds and the light exposures which altered the hue of the light, results show very similar results when comparing the RPM of tics during the different lights compared to the previous calculations, although the RPM of tics under Green, Red and Blue lights, were different.

Again, the results show that the participant experienced more tics per minute under Green, although in this case, the RPM of tics is lower than before (G=4.49, Range 1.69-7.02 tics per minute) compared to any other lights. There were no variations under Fluorescent Light, so results show that the participant suffered fewer tics under Fluorescent light (F=1.00, Range 0.22-2.8 tics per minute) than under any other light. This finding indicates that the source and colour of the light could have an impact on the behaviour of the participant. During Red the RPM of tics increases, a little bit (R=2.25, Range 0.24-4.55 tics per minute) and Blue (B=3.75, Range 0.12-6.55 tics per minute) and Participant J also experienced lower RPM of tics compared to White (W=4.03, Range 1.25-7.2 tics per minute) and Yellow s (Y=3.58, Range 0-10.8 tics per minute).

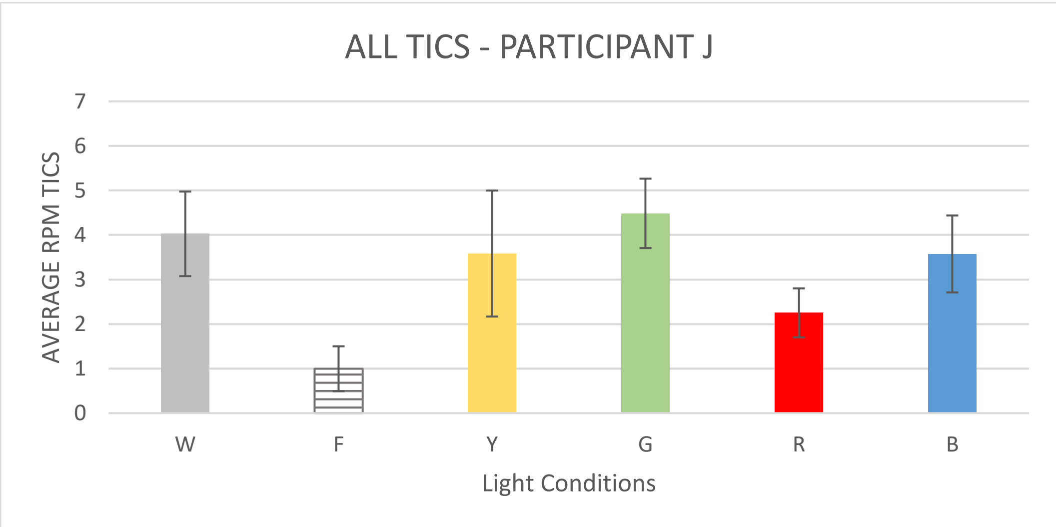


Figure 5. 72. Average RPM of motor and phonic tics combined under different light conditions which lasted more than 30 seconds and which maintained the properties of the light intact obtained for Participant J during the case study.

In this case, although the sample is very small, the duration of the exposures and the hue seemed to moderately alter the impact the light has in the rate per minute of repetitive behaviour, although the relationship of the results between the other lights remains similar.

5.4.5. Comparison across participants: RPM of tics

In terms of the source of the light (fluorescent and LED) and its influence on the rate per minute of repetitive behaviour, two out of four participants registered more RPM of tics under Fluorescent light, and White light – Participant F and Participant H. Opposite results were observed for Participant FX and Participant J, who registered lower RPM of tics under Fluorescent light than under White light. Table 5.73 shows under which source of the light - fluorescent (F) or LED (W) – the participants experienced lower (-) or higher (+) RPM of tics.

RPM TICS

	W	F
F	(-)	(+)
FX	(+)	(-)
H	(-)	(+)
J	(+)	(-)

Figure 5. 73. Level of RPM of tics under two different sources of the light (Fluorescent (F) or LED (W)) for each participant (F, FX, H and J).

In terms of the influence of the colour of the light in the RPM of tics, every participant was influenced by any of the coloured lights differently. Table 5.74 shows the RPM of tics observed under the different coloured light conditions for every participant. The levels of RPM of tics are represented with four different symbols:

- The colour which presented higher RPM of tics is represented with the symbol: (++).
- The colour which presented lower RPM of tics is represented with the symbol: (--)
- The second colour, which presented higher RPM of tics, is represented with the symbol (+).
- The second colour, which presented lower RPM of tics, is represented with the symbol (-).

RPM TICS

	Y	G	R	B
F	(-)	(- -)	(++)	(+)
FX	(-)	(+)	(- -)	(++)
H	(++)	(- -)	(-)	(+)
J	(+)	(++)	(- -)	(-)

Figure 5. 74. Level of RPM of tics under four different coloured lights (Yellow (Y), Green (G), Red (R) and Blue (B)) for each participant (F, FX, H and J).

Results show that the influence of the colour and source of the light on the RPM of tics was different between all the participants, but few similarities were observed.

Participant FX and Participant J experienced lower RPM of tics under Red conditions. Both participants had a high RPM of tics under Green. However, while Participant J had the highest RPM of tics under Green compared to any other light, Participant FX had the highest RPM of tics under Blue.

Participant F and Participant H experienced lower RPM of tics under Green conditions.

Results also show other differences. For example, while participants FX and J had more tics under Yellow and Green lights, with a subtle prevalence of tics when Green was set, Participant F had the lowest RPM of tics under these lights. Finally, while participants FX and J had the lowest RPM of tics under Red light compared to the other coloured lights, Participant F's RPM of tics was higher under Red than under any other LED light.

On the other hand, the results of Participant H showed a subtle variation between the RPM of tics depending on the colour of the light. However, as the difference between them is so small, less than half a tic per minute, results indicate that either the RPM of tics might not be an excellent behavioural factor to study or the colour of the light could have not a substantial impact on the RPM of tics for Participant H.

These results indicate that the colour and source of the light could have an impact on the RPM of tics, although it might be different depending on the participants. The findings mentioned indicate that there might be consistency between participants but also that other participants could react oppositely.

Figure 5.75 shows the summary of the results of the RPM of tics of the four participants in which we can see the similarities and the differences between them which were mentioned above.

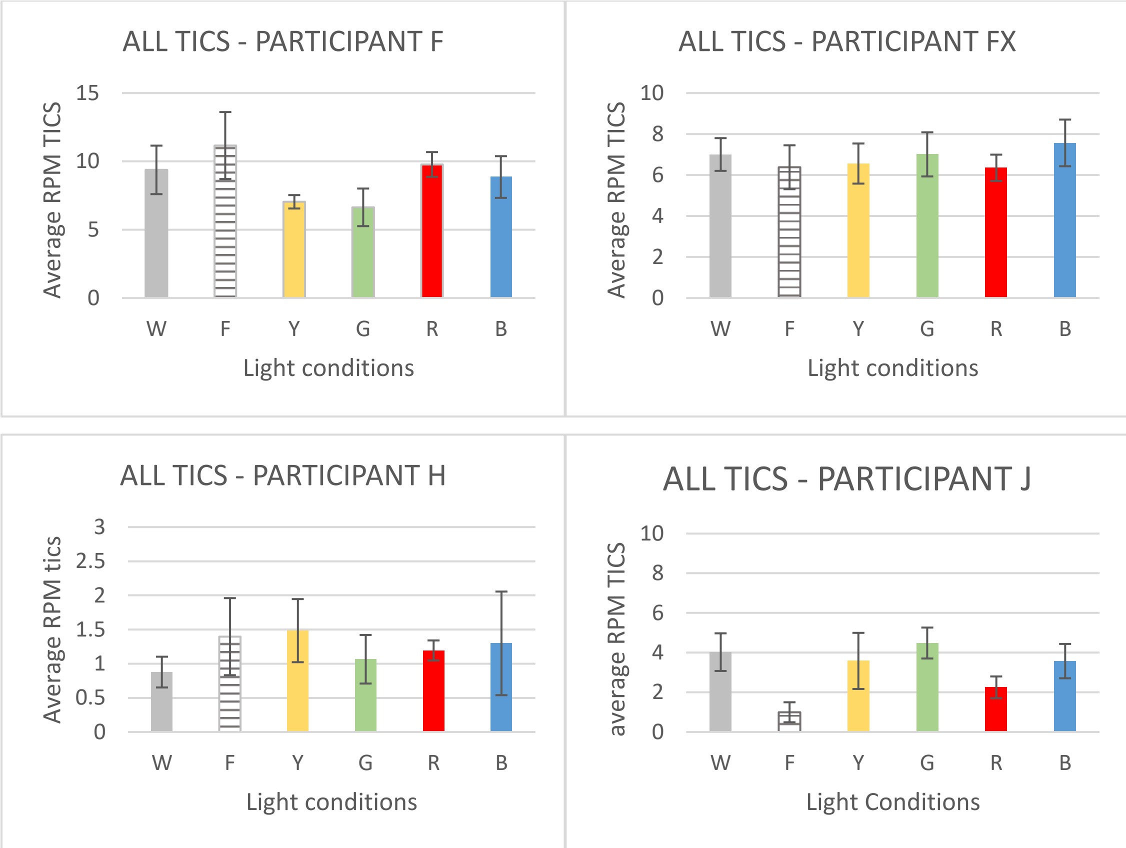


Figure 5. 75. Comparison of the RPM of motor and phonic tics combined under different light conditions obtained for all the participants during the case study.

As there were only four participants, any results obtained in this experiment can only be considered as preliminary results.

In terms of the rate per minute of repetitive behaviour or tics, similarities were not found between any of the four participants. This fact evidences that, first, the RPM of tics depends very much on the participant and, second, that the RPM of tics could act as a third cross-check to understand how the light influences the mood and the behaviour of the participants. Consequently, the combination of the EDA information, the temperature of the tip of the nose and the behavioural analysis is vital to understand how the light influences the participant and if the similarities found, are, in fact, similar as well in meaning. The combination of the three measures will be discussed in Chapter Six and Chapter Seven.

5.5. Comparison across signals:

The signals are considered to be consistent with each other when a specific physiological measurement such as EDA, shows a relationship between colours similar to the results obtained from other physiological signals such as the temperature of the tip of the nose or the RPM of tics. The relationship between colours can be diverse and equally consistent. For example, when comparing the effects between different lights, the signals will be consistent as long as we observe a change in behaviour depending on the colour of the light and we see this change as well in the other physiological measurements. Whether both signals tend to increase, or one increases and the other decreases, or both decrease might indicate the emotional or cognitive meaning of this change in the signal.

Combining the three signals has many advantages. First, we see if the signals are contaminated by other factors or, on the contrary, they are reliable independently. For example, when a particular pattern is repeated, it can indicate a consistency in the behaviour of the participant or, sometimes, it could be due to errors in the device which are imperceptible to the eye. If the signals are consistent, we can assume that the device provided us with accurate, objective and reliable information. Second, combining the signals give us more valuable information about the behaviour of the participant. As mentioned before, an increase in the skin conductance might indicate joy, stress or concentration. However, these three behaviours are very different and require different approaches. When combining the information with the temperature of the tip of the nose, for example, we can elucidate if a particular participant is feeling one thing or the other. For example, if the temperature of the tip of the nose increases, with an increase in skin conductance, we might be observing positive feelings such as joy as an increase in arousal might indicate joy, among other arousing feelings (Vrana & Rollock, 2002) but a decrease in temperature of the tip of the nose might be associated with negative feelings (Ioannou et al., 2014; Panasiti et al., 2016) therefore, an increase in the temperature might indicate positive feelings. If, on the contrary, the temperature of the tip of the nose decreases, it can mean concentration or stress. Then, if we add a third variable, in this case, the RPM of tics, we can elucidate if the behaviour is one or the other. Third, combining the signals over the days also enables us to decide whether we rely on the mean of the data and if we can extrapolate information or not. If the signals are consistent with the others, we might be able to rely on calculating the mean of the different measurements and consider this information could be useful to predict certain behaviours in the future.

For these comparisons, tonic EDA is used as it responds to long-term situations as the other two measures.

5.5.1. Participant F:

Results obtained from Participant F daily indicate that the three different physiological signals are consistent with each other 66,67% of the times. Only 16.67% of the times the signals were not consistent with each other. The rest of the times, the measures were consistent but partially. These findings indicate that all three signals might be reliable to measure the behaviour and mood of Participant F individually but also combined.

For example, Figure 5.76 shows both tonic EDA and temperature and RPM of tics on day 9. The Figure shows how tonic EDA increases when Red is on. At the same time, the temperature of the tip of the nose is higher under Red, while the tics are lower as well, indicating that the participant might feel more stressed under Red than under Green or Yellow which shows similar results.

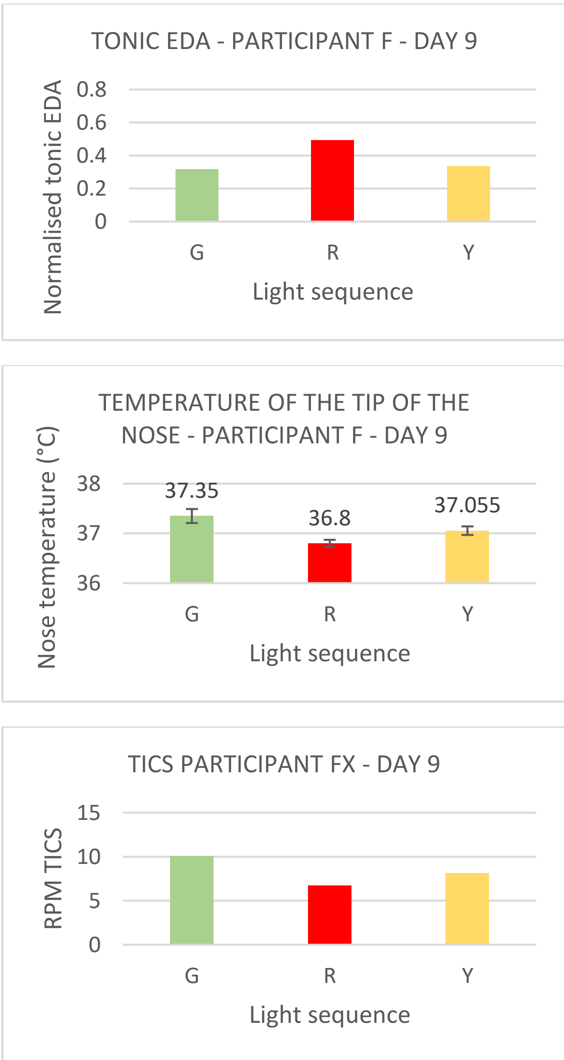


Figure 5. 76. Tonic EDA, average temperature of the tip of the nose and RPM of tics from Participant F on day 9.

When signals are only partially consistent, a signal can be consistent with one but not with the other as data from day 11 indicates in Figure 5.77. On day 11, tonic EDA and the temperature of the tip of the nose are consistent as both show similar trend. However, they are not consistent with the results obtained about tics under Fluorescent light which deviate from the pattern.

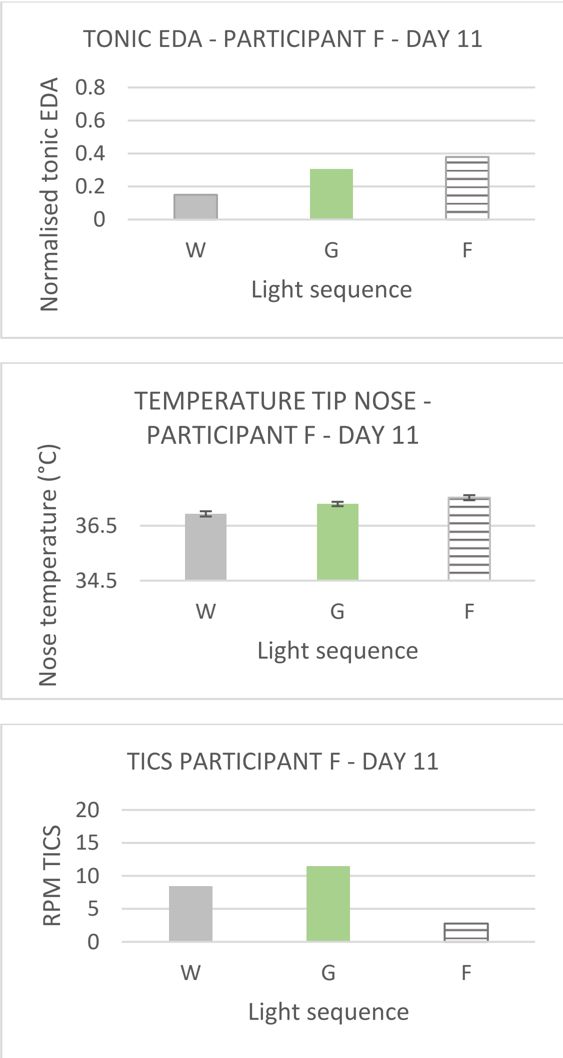


Figure 5. 77. Tonic EDA, average temperature of the tip of the nose and RPM of tics from Participant F on day 11.

When comparing the mean tonic EDA, mean temperature of the tip of the nose and the RPM of tics observed during all the case study, results show that the signals are consistent with each other for Participant F under all the lights except Yellow. Under Yellow, results to show that the RPM of tics is lower than expected compared with the other results (Figure 5.78).

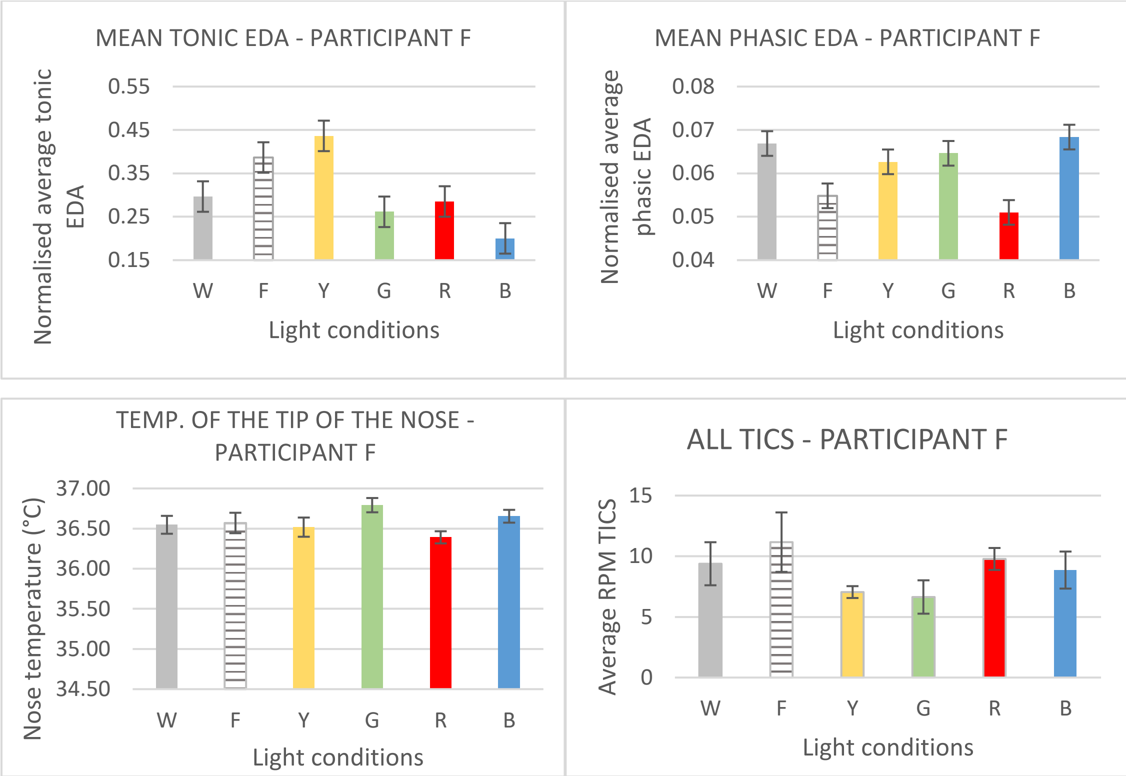


Figure 5. 78. Comparison of the mean EDA, mean temperature of the tip of the nose and rate per minute (RPM) of motor and phonic tics combined under different light conditions obtained for Participant F during the case study.

5.5.2. Participant FX:

Results obtained from Participant FX daily indicate that there were no inconsistent signals for Participant FX. The three different physiological signals are consistent with each other 33.33% of the times. However, 41.67% of the times, the three signals are consistent but with few exceptions.

For example, on day 4, tonic EDA and the temperature of the tip of the nose are consistent. However, the RPM of tics under Red are higher than expected and deviates from the rest (Figure 5.79).

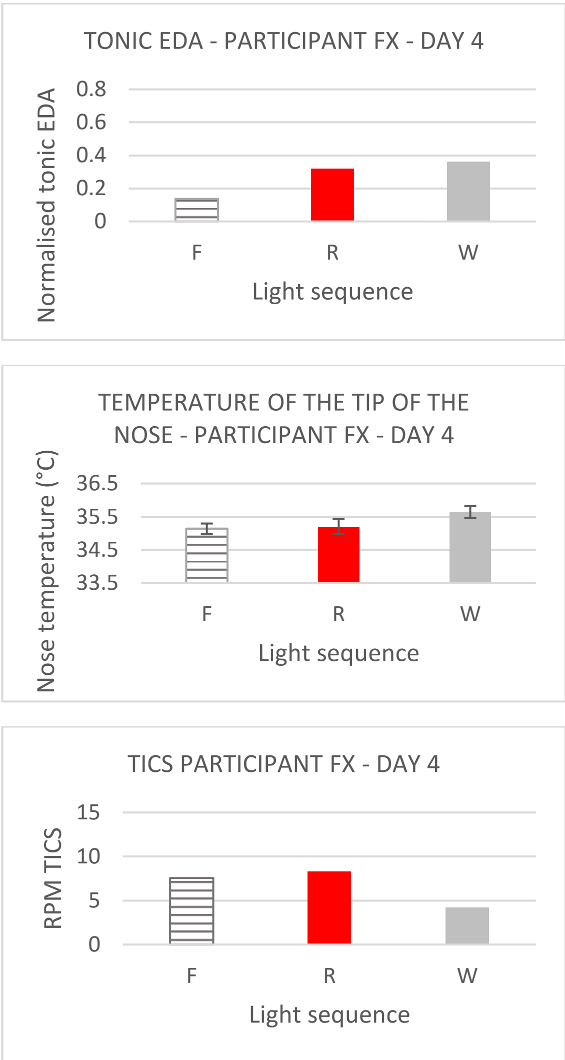


Figure 5. 79. Tonic EDA, average temperature of the tip of the nose and RPM of tics from Participant FX on day 4.

Moreover, 25% of the times, signals are only partially consistent, as a signal can be consistent with one of them but not with the other. For example, on days 10 or 12 (Figure 5.80), tonic EDA is consistent with the temperature of the tip of the nose, but it is not consistent with the RPM of tics.

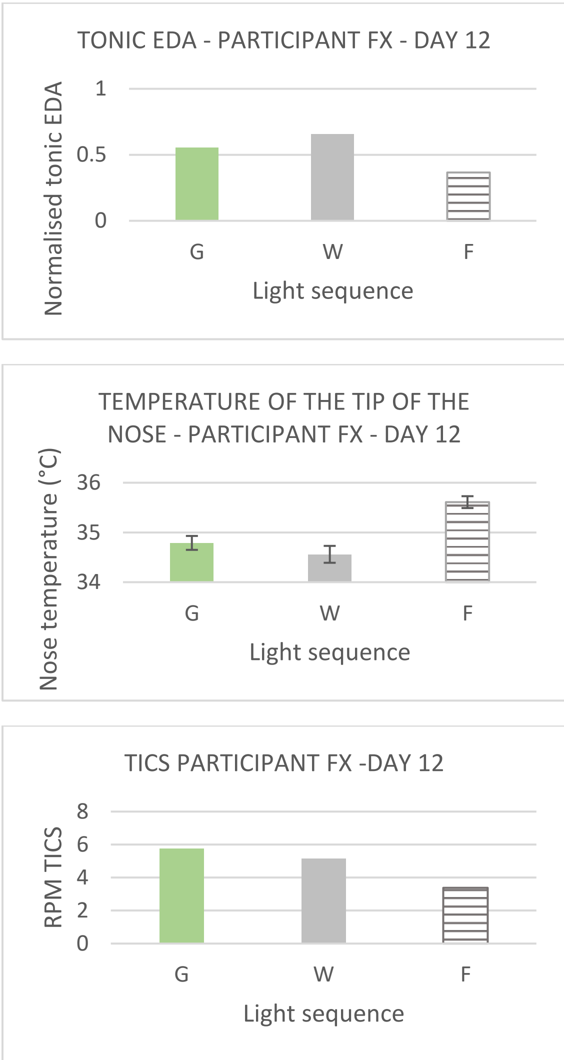


Figure 5. 80. Tonic EDA, average temperature of the tip of the nose and RPM of tics from Participant FX on day 12.

These findings indicate that all the three signals might be reliable to measure the behaviour and mood of Participant FX individually but also combined, always bearing in mind these little variations. When comparing the mean tonic EDA, the mean temperature of the tip of the nose and the RPM of tics, results show that the signals are consistent with each other for Participant FX (Figure 5.81).

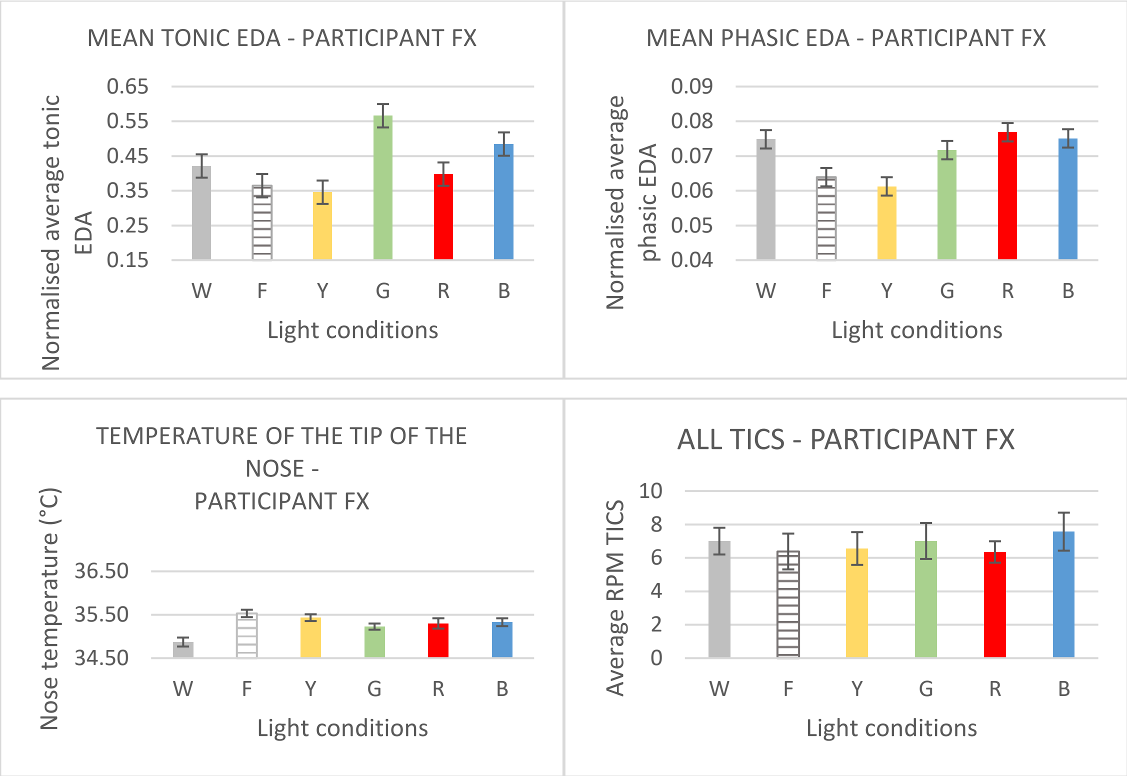


Figure 5. 81. Comparison of the mean EDA, mean temperature of the tip of the nose and rate per minute (RPM) of motor and phonic tics combined under different light conditions obtained for Participant FX during the case study.

5.5.3. Participant H:

Results obtained from Participant H daily indicate that the three different physiological signals are consistent with each other 60% of the time, and 40% of the time signals are partially consistent, as a signal can be consistent with one of them and exclude the other. There were no times when the signals were not consistent with each other. These findings indicate that all three signals might be reliable to measure the behaviour and mood of participants individually but also combined.

On days 4 or 7 (Figure 5.82), for example, tonic EDA is consistent with the RPM of tics, but not with the temperature of the tip of the nose.

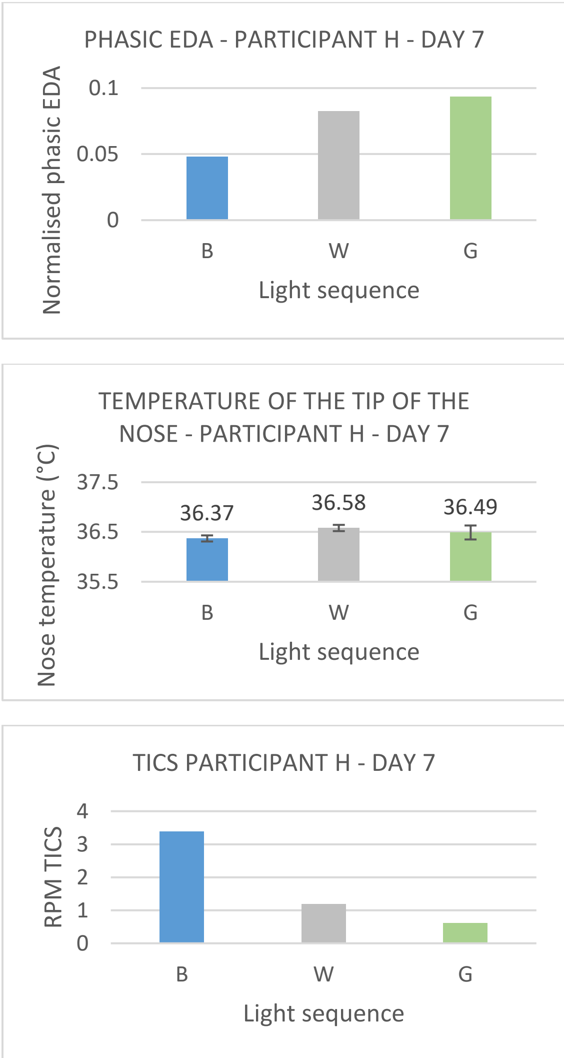


Figure 5. 82. Tonic EDA, average temperature of the tip of the nose and RPM of tics from Participant H on day 7.

When comparing the mean tonic EDA, mean temperature of the tip of the nose and the RPM of tics, results under White Fluorescent light, Yellow, Green and Blue, show that the signals are consistent with each other for Participant H. However, the temperature of the tip of the nose under Blue, or the RPM of tics under Green, do not seem consistent (Figure 5.83).

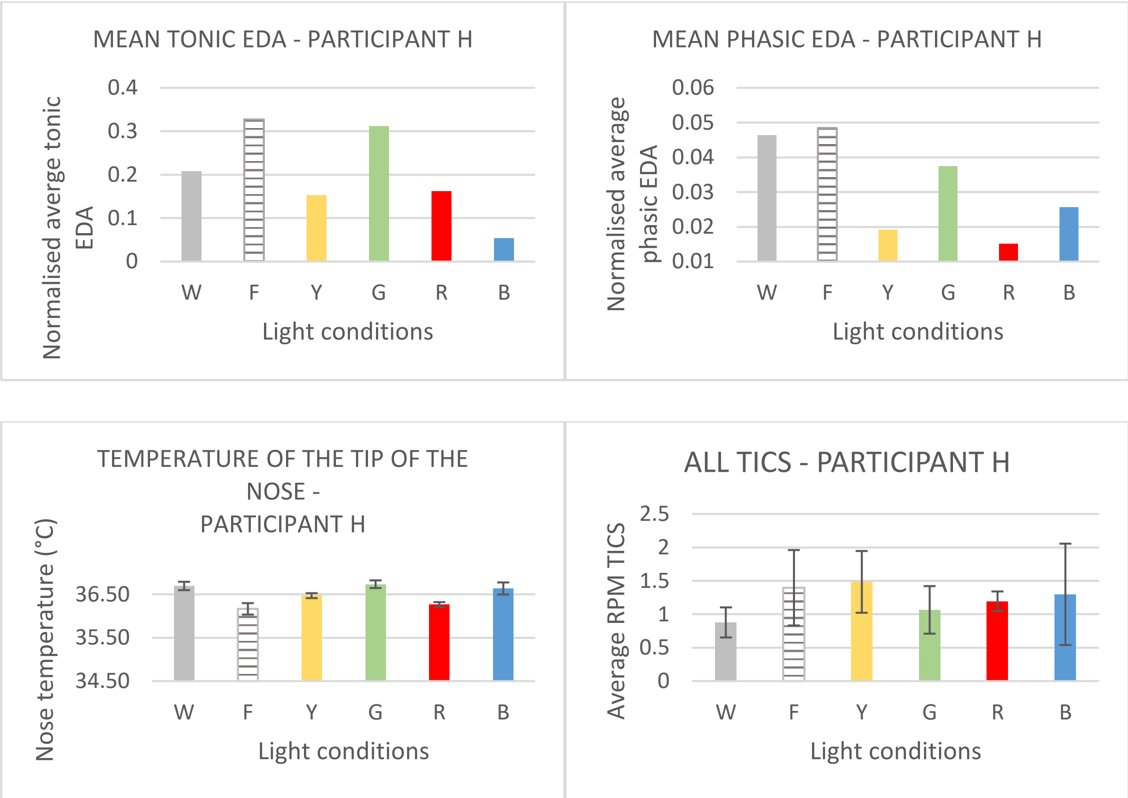


Figure 5. 83. Comparison of the mean EDA, mean temperature of the tip of the nose and rate per minute (RPM) of motor and phonic tics combined under different light conditions obtained for Participant H during the case study.

5.5.4. Participant J:

Results obtained from Participant J daily indicate that the three different physiological signals are consistent with each other 27.27% of the time, and 18.18% of the time, the three signals are consistent with the others but with a few exceptions.

For example, on day 13, measures of tonic EDA and RPM of tics are all consistent but the temperature under Blue deviated from the rest (Figure 5.84).

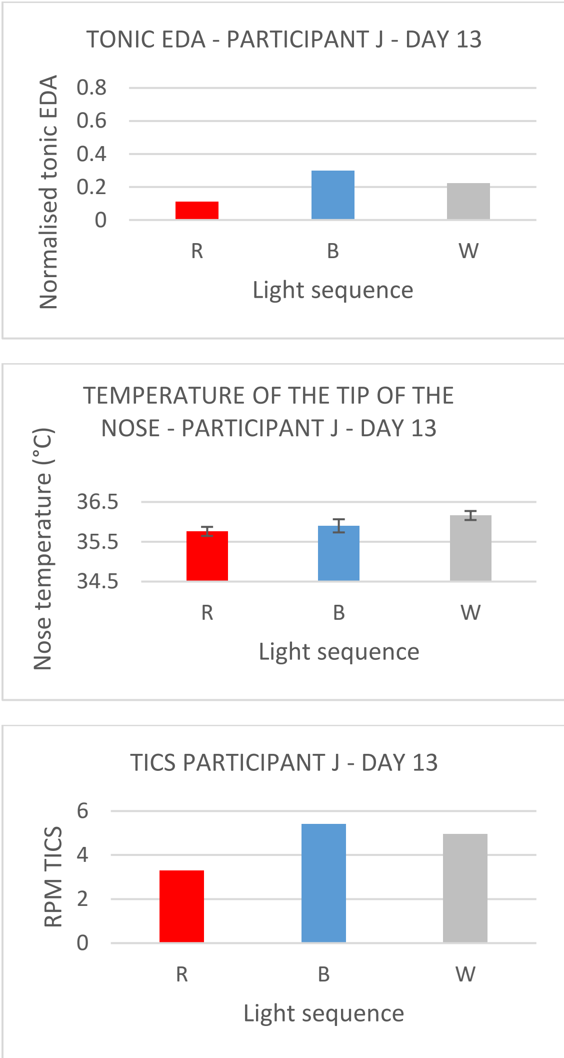


Figure 5. 84. Tonic EDA, average temperature of the tip of the nose and RPM of tics from Participant J on day 13.

45.45% of the times, signals are partially consistent, as a signal can be consistent with one of them but not with the other. For example, on days 4, 8 and 11, tonic EDA is consistent with the temperature of the tip of the nose, but the RPM of tics is not consistent with them. Figure 5.85 shows the data obtained on day 4.

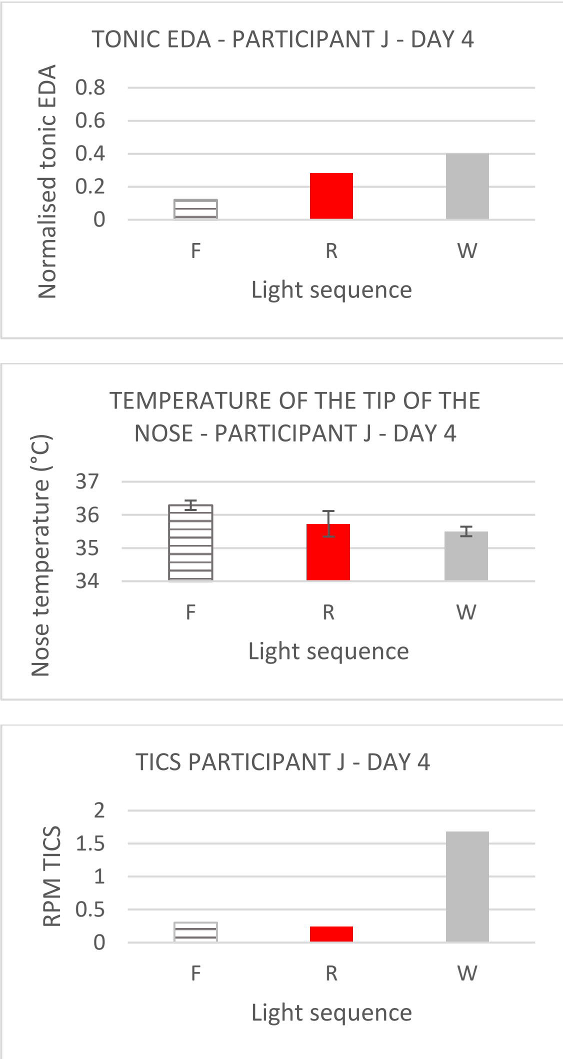


Figure 5. 85. Tonic EDA, average temperature of the tip of the nose and RPM of tics from Participant J on day 4.

These findings indicate that all the three signals might be reliable for measuring behaviour and mood of Participant J individually but also combined, always bearing in mind these little inconsistencies.

When comparing the mean tonic EDA, mean temperature of the tip of the nose and the RPM of tics, results show that the signals from the tip of the nose and the RPM of tics are consistent with each other under all the lights except Fluorescent light. Participant J had a lower RPM of tics under Fluorescent light than expected, considering the other signals, and higher RPM of tics under Green than expected (Figure 5.86).

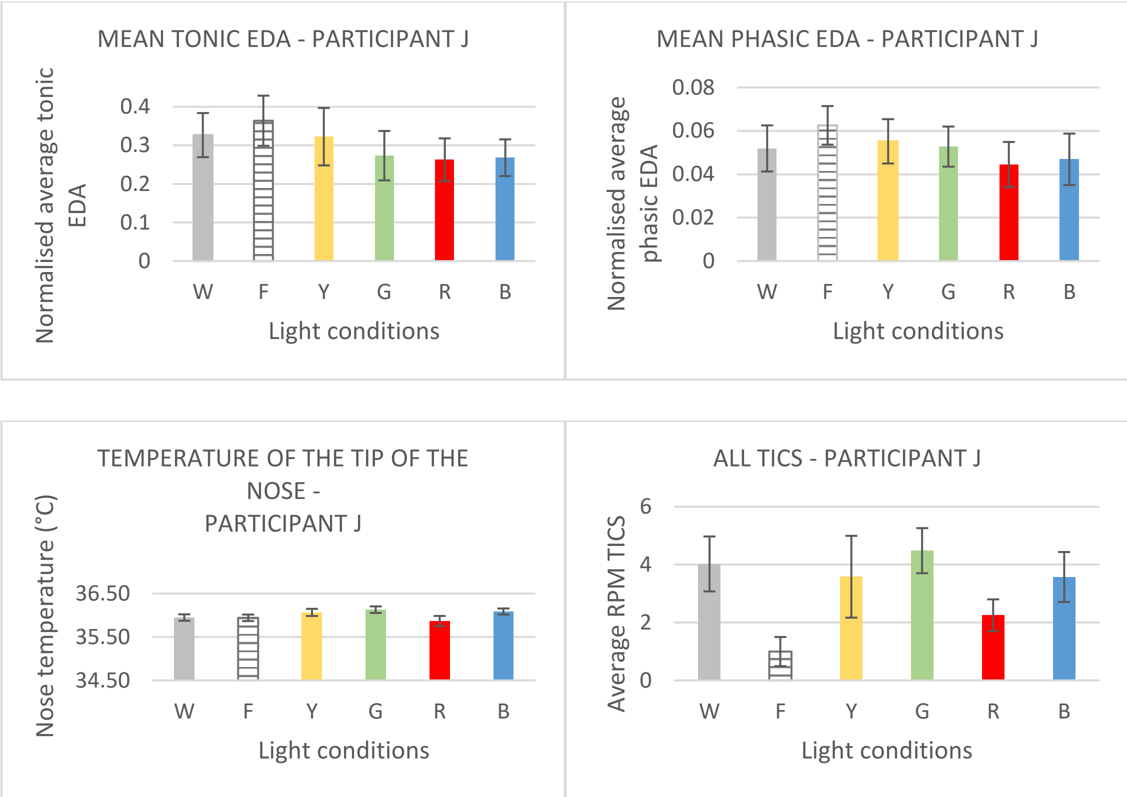


Figure 5. 86. Comparison of the mean EDA, mean temperature of the tip of the nose and rate per minute (RPM) of motor and phonic tics combined under different light conditions obtained for Participant J during the case study.

5.6. Chapter inference:

In order to understand the influence of the source or colour of the light might have in children with autism, an experiment was carried out to analyse the reactions of four children with ASD under different light conditions. The experiment consisted of thirteen 15-minute sessions in which the participants experienced different light conditions while doing activities that amused them. In the meantime, EDA and the temperature of the tip of the nose were measured, as well as video cameras were recording the scene for later analysis of the repetitive behaviour responses.

According to the results, the different lights seemed to have a different impact on the physiological and behavioural measurements of the children. Even though the reactions are different for every participant, some similarities were found between the physiological signals of participants. Being able to record more than one physiological signal and to analyse the repetitive behaviour was crucial to identify nuances in the responses and understand the possible real meaning of the results and see if there are significant similarities which could inform future research.

Nevertheless, the results exposed in this chapter come from only four participants, and each participant has a particular signature in the set of effects that were measured, which is distinct from the other participants. There is a vast disparity between people with autism in terms of their condition and responses to stimuli in general; therefore, any generalisation would need to be treated with great caution. The first point is to determine an understanding of how individual people with autism respond to stimuli, and that is what these experiments have sought to explore.

Therefore, so far, it can only be possible to extract preliminary results from each participant in particular that cannot be extrapolated to the whole spectrum. For example, while Blue seemed to be a high arousing colour for Participant FX, it seemed to be a low arousing light for Participant F. Even though both participants might feel positive about the light according to the results of the temperature of the tip of the nose, the measurements of the EDA and the behavioural analysis showed that the emotions that this light can induce in the participants might have different nature.

The fact that the different lights have a different impact on a participant would indicate that potentially, controlling the light colour might have beneficial outcomes because participants respond to different colours in distinctive ways. However, the fact that the patterns are different across the participants showing that there is no single general rule about which colour elicits which response for all participants, indicates that the design solutions should be bespoke and individual.

As previously seen during this chapter, the physiological signals and the behavioural analysis observed individually lacked the meaning needed to understand the inner emotions involved in every light exposure. In the following chapter, Chapter Six, an experimental procedure to combine the three body signals is proposed. It is expected that this method could help with understanding the different emotions that the different lights could provoke in the different participants without the need of using self-report questionnaires or subjective responses.

CHAPTER SIX - EXPERIMENTAL METHOD "3D MOOD BOX"

6.1. Introduction

As mentioned in Chapters Three and Four, four children were monitored and observed while playing with toys under different light conditions, in order to understand how the different colours and sources of light might impact on their mood.

In Chapter Five, results obtained from the physiological signals (electrodermal activity, facial thermography and rate per minute of tics) were exposed and compared. The results were revealing in many ways. First of all, each of the three physiological signals experienced variations depending on the colour and source of the light. Secondly, although some similarities were found between participants, the results of every participant showed that the colour and source of the light might affect every individual differently. Third, even though the factors studied seemed to influence all the physiological signals, every signal becomes meaningless, in terms of mood, if they are observed in isolation.

Although the results thus obtained could indicate something about parasympathetic reactions related to the mood of the participants when experiencing the different light conditions, they need to be studied in combination to obtain a more comprehensive understanding of the influence of the colour and source of the light might have in the mood.

In this chapter, a three-dimensional analysis that combines the three types of objective information gathered during the experiment is presented. All the characteristics of the approach and the steps followed to obtain the results for every participant, as well as how this three-dimensional dataset has to be read, are explained before showing the results about the mood of the four participants under different light conditions.

6.2. History about emotions:

It has always been challenging for psychologists to define, identify and measure an emotion. In 1884, William James tried to establish a definition for “emotion”, stating that the physiological change occurs first, and then emotion results from the brain reacting to the physiological change via the body’s nervous system. In other words, the physiological arousal provokes the experience of emotion, instead of first feeling the emotion and then experiencing the body response afterwards. This interpretation is known as the James-Lange theory (James, 1884). Lisa Feldman Barret (Feldman Barrett, 2017), on the contrary, considers that every emotion is subjective and depends very much in the context and social cues. Although both points of view were made more than a century apart, trying to define what is an 'emotion' is still an unfinished debate that continues nowadays. According to Klaus R. Scherer, the debate has not finished yet because the concept of “emotion” is generally attached to the evolution of language and usually based on subjective analysis.

Contemporary researchers limit themselves to the arousal and the emotional valence dimensions. This current approach provides with the well-known circular mapping of emotions that proposed Scherer in 2005 (Scherer, 2005) (Figure 6.1) based on the circular mapping that Russell (1983) proposed.

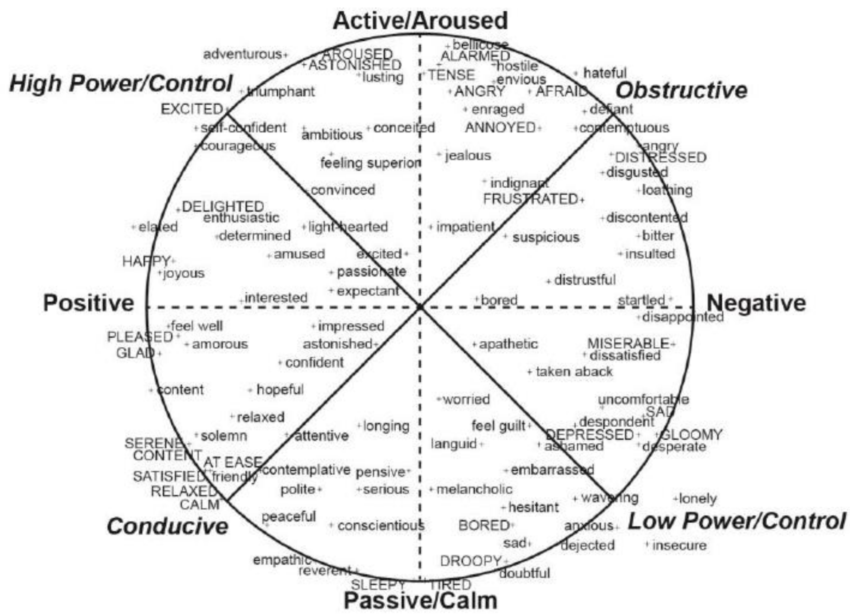


Figure 6. 1. Dimensional structure of the semantic space for emotions based on arousal y emotional valence proposed by Scherer (2005).

A possible drawback of this approach might be that it is based on self-report questionnaires whose answers are subjective and, for instance, not always accurate and very difficult to compare. Different participants can evaluate their arousal differently, and the results might be confusing.

Not only might the results lead to confusion, but this type of approach might not be the most appropriate in some cases, such as with people with severe autism. Low functioning people with ASD like the participants who collaborated in the study, who are non-verbal and have learning disabilities might be unable to answer the questions these methods use (as indeed was the case in this instance).

The difficulty in getting responses to questionnaires from particular participants can be counteracted by using objective data. Because of the challenges with communication for people with autism, avoiding subjective tools such as self-report questionnaires was one of the main goals and challenges of this research. For this reason, all the tools used to understand the mood of the participants were those who provided physiological responses or spontaneous and unconscious behaviour such as tics. Yet it is also necessary to link these physiological responses to some sense of emotion or mood, in order to understand better how the participants 'feel', rather than just make assumptions about that. William James advocated the idea that physiological changes happened before the emotion. However, it is important to recall that the context of every individual would also play an important role in the emotions, as Barret suggested. In this study, it is interpreted that the environment, along with the context of every participant, are all factors that influence the physiological signals differently, thus provoking different emotions.

According to Shu et al. (Shu et al., 2018) many researchers attempted to identify emotions by analysing physiological signals and using different kinds of models. Although 2D models are widely used because they can easily help to distinguish negative and positive emotional responses, these models do not differentiate between different kinds of negative or positive feelings. For this reason, Mehrabian (Mehrabian, 1997) proposed a 3D model based on arousal, valence and dominance to identify more accurately emotions, although it was not the first 3D model approach used to identify emotions. Wilhelm Wundt, the German experimental psychologist, presented his "tridimensional theory of feeling" in 1893 in the fourth edition of his *Physiological Psychology* (Wundt, 1905). His model was based on emotional valence, arousal and tension.

The concept being explored in this chapter is that the combination of the three signals might inform objectively about the predominant emotions that the participant might feel under different light conditions. For example, when comparing the impact of the colour of the light on the arousal of one participant under Blue, White and Green lights, as seen in Figure 6.2, it can be observed that Green is the more arousing colour light.

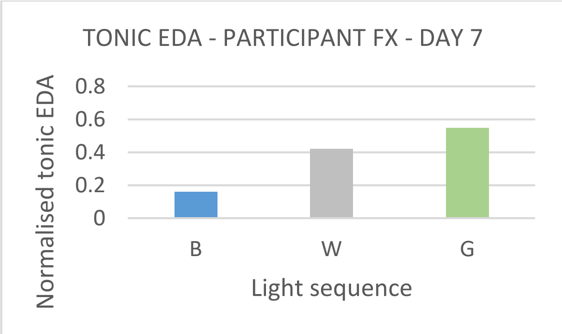


Figure 6. 2. Example of tonic EDA under Blue (B), White (W), and Green (G).

The increased arousal could indicate stress, happiness, excitement or mental workload. These emotions have very different natures and outcomes, and that is why having another physiological signal to see whether the emotion is positive or negative is crucial. If comparing the EDA data with thermography, it is possible to elucidate whether the feeling is positive or negative. If the temperature rises, it shows positive feelings such as excitement and happiness, whereas if the temperature lowers, it shows mental workload or negative feelings such as stress. Figure 6.3 shows that the temperature of the tip of the nose under Green conditions is almost 0.50°C higher than the temperature registered under White. That would indicate that the emotion felt under Green was excitement or happiness, instead of stress or mental workload.

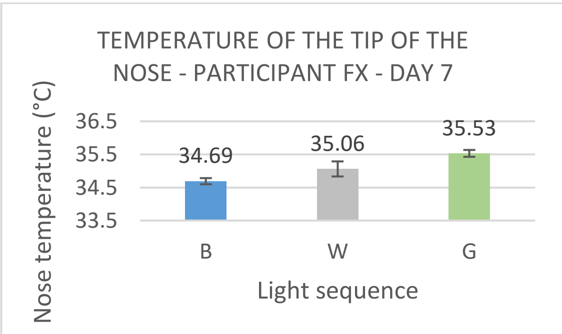


Figure 6. 3. Example of temperature under Blue (B), White (W), and Green (G).

The RPM of tics acts as a third-check to define better the emotion that the participant is feeling. Therefore, in this case, the RPM of tics can help to elucidate whether the participant is feeling excitement or happiness. An increase of RPM of tics would indicate excitement, while a decrease in the repetitive behaviour would indicate happiness and contentment. As shown in Figure 6.4. the RPM of tics under Green is lower than under the other light conditions; therefore, it can be said that the participant tend to feel happiness under Green.

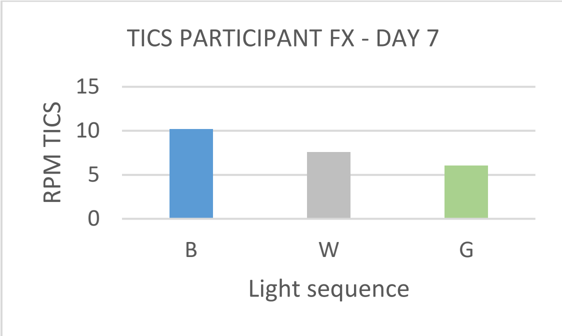


Figure 6. 4. Example of RPM of tics under Blue (B), White (W), and Green (G).

In order to combine the three pieces of objective information automatically, a new model is proposed. This new approach consists of a three-dimensional space formed by three dimensions that helped to categorise the different emotions. This model is called **3D Mood Box**. While other three dimensional models such as the one created by Wilhelm Wundt (1905) or Mehrabian (1997) are theoretical models to identify emotions, the 3D Mood Box provides an actual measurable direction to identify when the participant is feeling a predominant feeling compared to other circumstances.

6.3. Three variables, three dimensions: the 3D Mood Box

To start with, an emotional/mood response is considered in the form of an 'emotional space'. The three dimensions of this space are composed of the three physiological signals gathered from the study and form the three-dimensional box called 3D Mood Box.

The first variable used is the electrodermal activity (EDA) of every participant. As the study focused on the long-term effects of the light in people's mood, tonic EDA was used for this purpose. The second variable is the temperature of the tip of the nose. The combination of the first two variables might often be enough to differentiate certain emotions and feelings. However, to clarify all the possible confusing situations, a third variable that acts as a third cross-check was added, and this third variable is used to solidify the results obtained from the other two variables. The third variable is the rate per minute of tics.

Dealing with people with severe autism, the analysis focused on the presence of tics for two reasons. The first reason was the fact that the presence of tics is a primary characteristic of the participants with ASD who participated in the experiment, and being this presence of tics sometimes detrimental on their daily life, testing if the colour and source of the light could minimise or strengthen these symptoms was vital. Even though these tics were different from every participant, they were easy to identify and quantify using software such as The Observer. Secondly, the possibility to measure the rate per minute of tics with non-invasive tools such as video recording analysis and not with invasive tools that could have influenced their performance.

The third variable could also have been other physiological signals such as heart rate (HR) or respiration rate (RR), or any aspect of the body language and behaviour that can be relevant and characteristic for the participant studied. For example, in terms of respiration rate, similarly to the RPM of tics, an increase in RR might indicate anger, anxiety, fear, happiness and joy and a decrease in RR might indicate affection, contentment, relief and sadness (Kreibig, 2010). However, for this case study, the rate per minute of tics was chosen as a more appropriate measure because it is less invasive and more aligned to the circumstances of the participants with severe autism who participated in the case study.

As previously seen in Chapter Five, these three different pieces of information cannot provide information enough on their own to identify emotions, but the combination of the three of them provides more details that could help to see the different types of emotions the participant could be feeling under different light conditions. These three measurements might also be practical options as they are not invasive and do not interfere with the participant's behaviour and performance of the activity.

A three-dimensional approach permits giving more shades to the information obtained. Wilhelm Wundt also proposed a three-dimensional space to identify emotions in 1905 (Wundt (1987), 1998). His approach was formed by the dimensions of emotional valence, arousal and tension. The approach he designed was based on self-report questionnaires. As it was particularly challenging for the participants to evaluate how tensioned they felt, this approach was not felt to be appropriate for psychologists, thus, two-dimension approaches became more popular.

In order to create from scratch a three-dimensional space to include the information gathered, there were many aspects that needed to be defined. As an initial convenience, it was decided to represent the space as a 'box' because this would allow a straightforward representation of the three dimensions. The first thing to define was the origin point of the box. The location of this point would, inevitably, modify all the features of the box.

6.4. The origin point

The three dimensions intersect at an origin point [0,0,0]. The coordinates of the origin point are the median values of every set of physiological and behavioural data gathered from each participant: tonic EDA (tEDA), the temperature of the tip of the nose (T) and the rate per minute of tics (Tics). The origin point serves to identify the possible standard emotional status of the person. For instance, the origin point [0,0,0] is unique for every person, X being the participant who is being studied:

$$[0,0,0]_{\mathrm{x}} = [\, Med\ tEDA_{\mathrm{x}}, Med\ T_{\mathrm{x}}, Med\ Tics_{\mathrm{x}}] \qquad (6.1)$$

The median was considered to be the best option after considering the mode and the mean, but these options were rejected for various reasons. On the one hand, the mode was rejected due to the nature of the information gathered. In all three physiological signals, accuracy and precision of two decimal places were crucial because the changes in physiological and behavioural signals can be reflected with a precision of two decimal places. Since the different sets of data covered voluminous different values, finding the mode was neither precise nor objectively informative.

On the other hand, the mean was dismissed in order to avoid unusual events contaminating the whole analysis. The daily and individual analysis of every physiological signal allowed us to identify radical pieces of information that could be caused by variables that could not be controlled during the experiment. For example, on days 2 and 4, the measurements of the temperature of the tip of the nose of participant F seemed to be exceptionally low compared to the others. For this reason, the mean of the signals could provide with inaccurate data for this purpose. Figure 6.5 shows the template of the three-dimensional box created with three dimensions of data collected that intersect in the origin point.

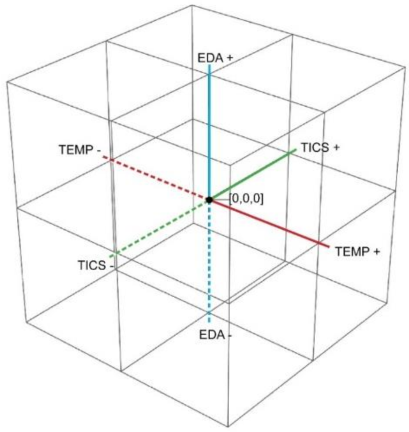


Figure 6. 5. Template of the three-dimensional box with origin point [0,0,0] identified and the axis and dimensions that create different quadrants.

6.5. The Quadrants:

The intersection of these three dimensions creates eight virtual quadrants. Each of these quadrants covers a possible data combination, considering the physiological values which tend to be higher or lesser than the median for every participant. A symbolic size has been given to the box to make the comparison of responses between different colours easier, so if the balls land inside the box or outside it, this is just a way to show the distance between the centre and origin point of the box and the point itself.

Every combination of data associated with every quadrant corresponds to different types of emotions and behaviours. For this reason, the location of the origin point is vital. The origin point might be considered as a reference point to indicate what might be the 'typical' behaviour.

However, even though every quadrant is associated with a group of emotions, it is essential to bear in mind that the quadrants do not inform about pure emotions. The quadrants and their meanings are considered as a tendency or prevalence of the participant to feel in a certain way compared to other possible emotional states registered during the case study. Therefore, the location of each dataset can only inform about possible emotional prevalence. Consequently, the feelings and emotions identified in the participants are not necessarily felt in isolation from other feelings which could be imperceptible to the naked eye.

Although some researchers might suggest that the physiological responses which are related to a feeling or emotions might not occur in the same way in other vulnerable populations such as adolescents with autism (Edmiston, 2016), for the purposes of this thesis, it has been considered that what applies to normative people in terms of physiological responses and emotions (i.e. stress or excitement is identified when an increase in the arousal is observed) would apply to people with autism the same way.

Moreover, the distance of any point of data from the origin point might provide an indication of the intensity of the feeling. The closest to the origin point any point could be considered as the more neutral and typical the feeling could be. The further from the origin that point any point is, the more obvious and exaggerated the feeling could be.

- Quadrant I (QI) is associated with positive feelings such as ***excitement and joy***.

  QI corresponds to the combination of values in which the temperature of the tip of the nose, EDA and RPM of tics tend to be higher than the median (see equation 6.2). This quadrant is located, as indicated in Figure 6.6. Regarding tonic EDA, according to Vrana et al. (2002), an increase in SCL might indicate joy. As Panasiti et al. (2016) suggested that the decrease in the nasal temperature might be associated with stress and anxiety, an increase of the temperature of the nose could suggest positive feelings such as joy, relaxation and pleasure. Moreover, an increase in the rate per minute of tics is associated with anxiety and excitement. Considering that the other variables indicate positive feelings if the RPM of tics increases when the other values accomplish the mentioned characteristics, the increase of the RPM of tics is also associated with joy and excitement.

$$\begin{gathered} tEDA > Med\ tEDA \\ T > Med\ T \\ TICS > Med\ TICS \end{gathered} \tag{6.2}$$

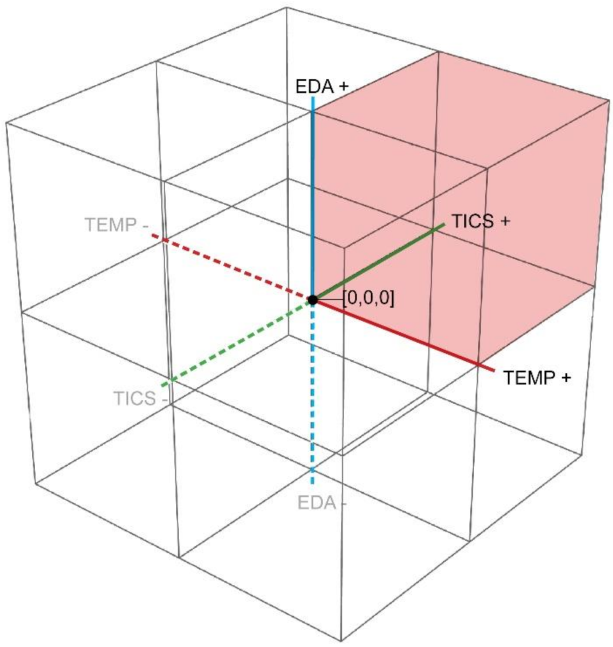


Figure 6. 6. Quadrant I (QI) in the 3D Mood Box.

- Quadrant II (QII) is associated with positive feelings such as **contentment, pleasure and *interest*.**

QII corresponds to the combination of values in which the temperature of the tip of the nose and the RPM of tics tend to be higher than the median, but the tonic EDA tends to be lower than the median (see equation 6.3). This quadrant is located, as indicated in Figure 6.7. Studies on the physiological response of contentment and pleasure show low levels of tonic EDA (Christie & Friedman, 2004; Hess et al., 1992; Palomba, Sarlo, Angrilli, Mini, & Stegagno, 2000). Similarly, a high temperature of the tip of the nose is associated with positive feelings.

$$tEDA < Med\, tEDA$$

$$T > Med\, T$$

$$TICS > Med\, TICS \tag{6.3}$$

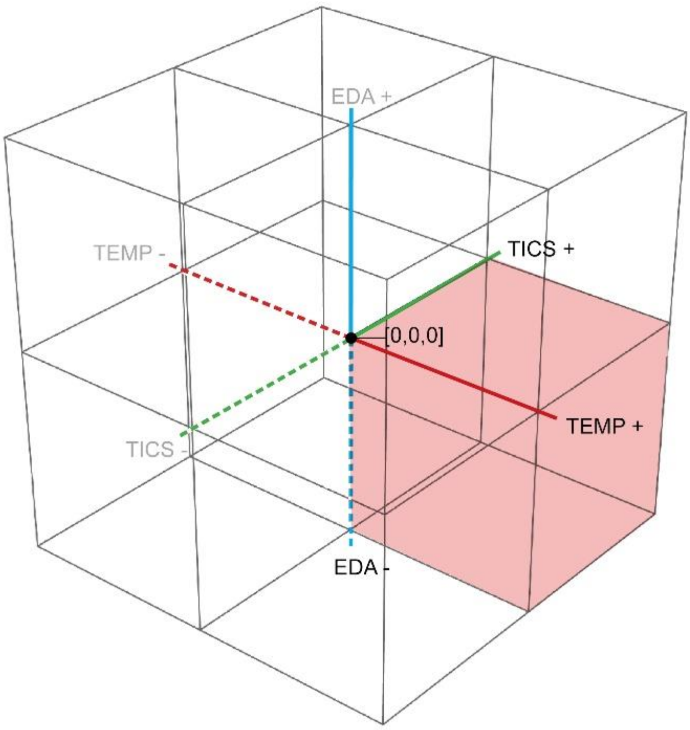


Figure 6. 7. Quadrant II (QII) in the 3D Mood Box.

- Quadrant III (QIII) is associated with positive feelings, such as ***happiness and amusement***.

  QIII corresponds to the combination of values in which the temperature of the tip of the nose and the tonic EDA tend to be higher than the median, but the RPM of tics tends to be lower than the median (see equation 6.4). This quadrant is located, as indicated in Figure 6.8. As seen before, an increase in both tonic EDA and increase in temperature of the tip of the nose is often associated with positive feelings such as excitement and happiness (Codispoti, Surcinelli, & Baldaro, 2008; Gehricke, 2002). An increase in tonic EDA is also linked to pleasure (Codispoti et al., 2008). However, while an increase in the RPM of tics could indicate excitement, a decrease in the RPM of tics could indicate positive feelings such as happiness.

$$tEDA\ >\ Med\ tEDA$$

$$T >\ Med\ T$$

$$TICS <\ Med\ TICS \tag{6.4}$$

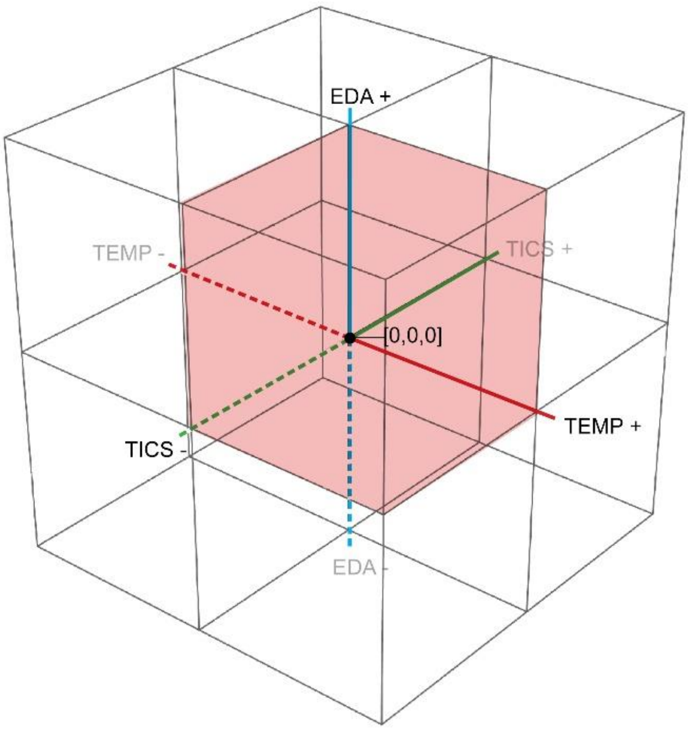


Figure 6. 8. Quadrant III (QIII) in the 3D Mood Box.

- Quadrant IV (QIV) is associated with positive feelings, such as ***relaxation*** **and** ***relief***.

  QIV corresponds to the combination of values in which the temperature of the tip of the nose tends to be higher than the median, but the tonic EDA and the RPM of tics tend to be lower than the median (see equation 6.5). This quadrant is located, as indicated in Figure 6.9. Merla et al. (2014) associated a drop in temperature of the tip of the nose with a feeling of guilt in children. For this reason, an increase in temperature indicates the contrary so that the participant might feel relaxed and relieved. A decreased tonic EDA has also been linked to relief, according to Blechert et al. (2006), and Chan and Lovibond (1996). Besides, a decrease in the RPM of tics or the absence of them is liked to relaxation and relief.

$$tEDA < Med\ tEDA$$

$$T > Med\ T$$

$$TICS < Med\ TICS \tag{6.5}$$

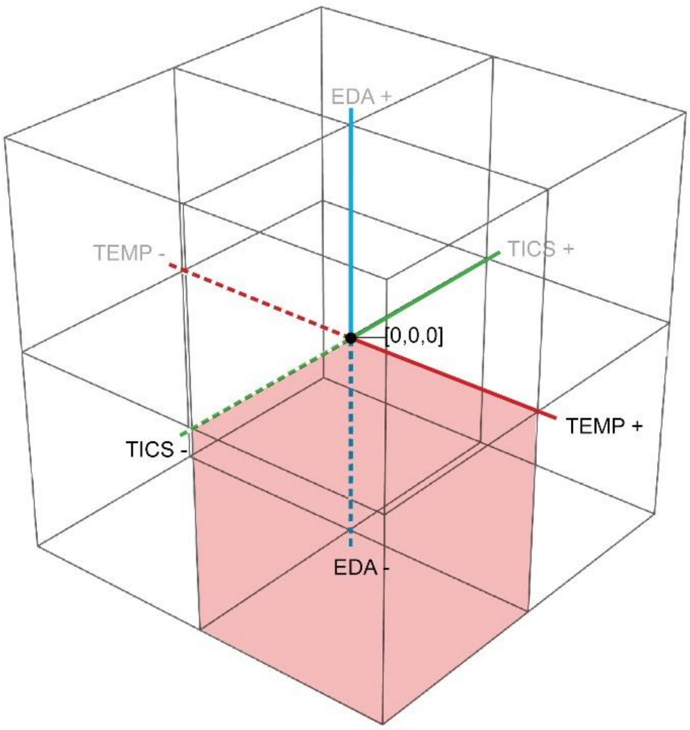


Figure 6. 9. Quadrant IV (QIV) in the 3D Mood Box.

- Quadrant V (QV) is associated with feelings such as ***alertness, concentration* and *mental workload***.

QV corresponds to the combination of values in which the temperature of the tip of the nose and the RPM of tics tend to be lower than the median, but the tonic EDA tends to increase (equation 6.6). This quadrant is located, as indicated in Figure 6.10. As seen previously, an increase in EDA is associated with excitement, stress and mental workload. Novak et al. (2010) showed that skin conductance increases when high demanding tasks are done. Moreover, a decrease in both temperature of the tip of the nose (Marinescu et al., 2018) and the RPM of tics (Harris & Singer, 2006) is also linked to concentration and mental workload. For this reason, if we have this combination of data, we can suggest the participant is focused on the activity.

$$tEDA > Med\, tEDA$$
$$T < Med\, T$$
$$TICS < Med\, TICS \qquad (6.6)$$

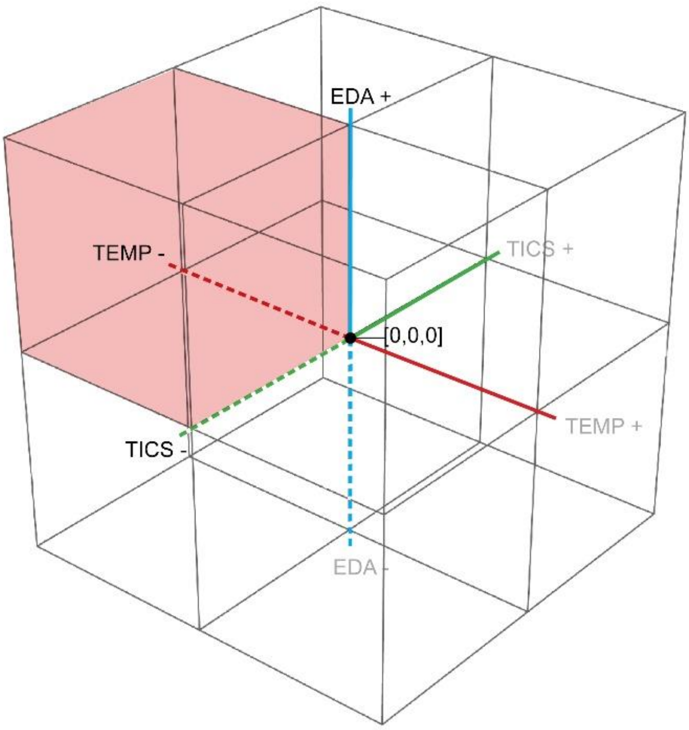


Figure 6. 10. Quadrant V (QV) in the 3D Mood Box.

- Quadrant VI (QVI) is associated with feelings such as ***distraction***.

  QVI corresponds to the combination of values in which the temperature of the tip nose, the tonic EDA and the RPM of tics tend to be lower than the median (see equation 6.7). This quadrant is located, as indicated in Figure 6.11. The only difference in the combination of data associated with QVI, compared to the data associated with QV is the lower skin conductance (EDA). Since the increase in skin conductance is associated to the mental workload while doing high demanding tasks (Novak et al., 2010), it has been suggested that, under the same circumstances, a decrease in skin conductance might mean distraction. Moreover, when a person with tic disorders is distracted, they also experience a reduction of tics. This feeling is not considered a negative feeling but a neutral feeling. However, in cases where therapists want the participant to be focused on the task, this combination of factors should be avoided.

$$tEDA < \; Med\, tEDA$$

$$T < \; Med\, T$$

$$TICS < \; Med\, TICS \tag{6.7}$$

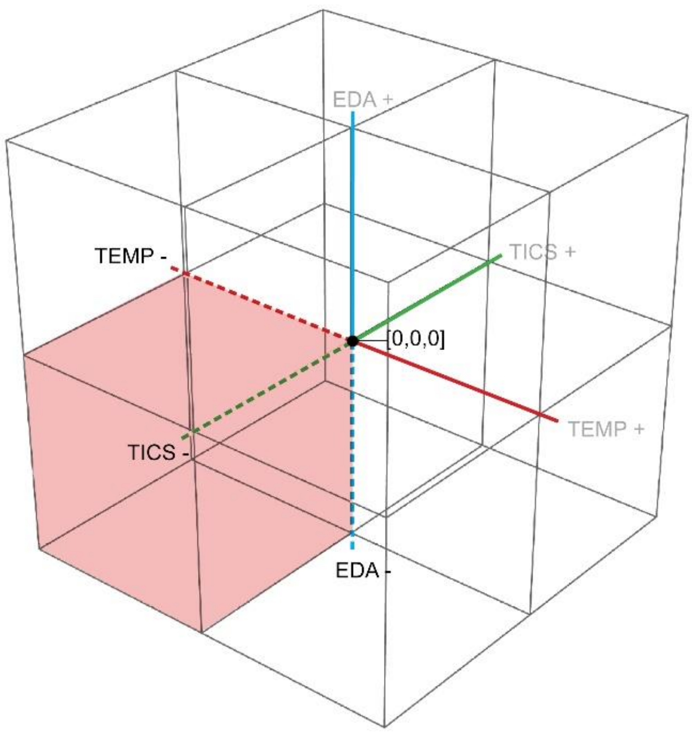


Figure 6. 11. Quadrant VI (QVI) in the 3D Mood Box.

- Quadrant VII (QVII) is associated with negative feelings such as ***anxiety, stress, anger and overstimulation***.

QVII corresponds to the combination of values in which the temperature of the tip of the nose tends to be lower than the median, but the tonic EDA and the RPM of tics tend to be higher than the median (see equation 6.8). This quadrant is located, as indicated in Figure 6.12. Regarding tonic EDA, according to Blechert et al. (2006), Chan and Lovibond (1996), Murakami and Ohira (2007) and Ritz et al. (2000), an increase in SCL indicate anxiety. Panasiti et al. (2016) suggested that the decrease in the nasal temperature might be associated with stress as well as an increase in the RPM of tics might be associated with anxiety.

$$tEDA > Med\ tEDA$$

$$T < Med\ T$$

$$TICS > Med\ TICS \tag{6.8}$$

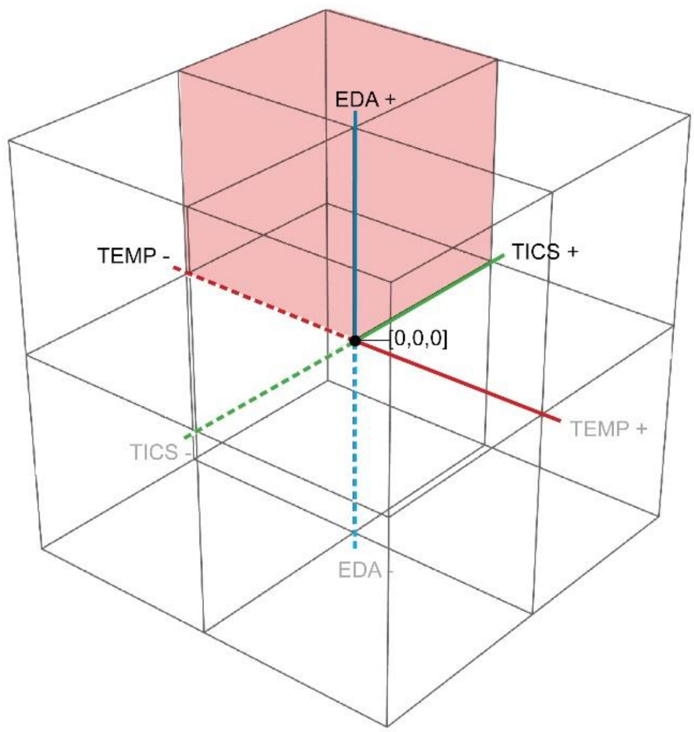


Figure 6. 12. Quadrant VII (QVII) in the 3D Mood Box.

- Quadrant VIII (QVIII) is associated with negative feelings such as ***frustration, annoyance, sadness and tiredness***.

  QVIII corresponds to the combination of values in which the temperature of the tip of the nose and the tonic EDA tend to be lower than the median, but the RPM of tics tends to increase (see equation 6.9). This quadrant is located, as indicated in Figure 6.13. According to Gehricke and Frindlund (2002) and Ekman et al. (1984), a decrease in the tonic EDA can be associated with sadness (when it does not involve crying (Ritz et al., 2005). The decrease in the temperature of the nose might indicate frustration that, combined with low EDA and high RPM of tics, suggests that the predominant feeling might be a mixture of low arousing and awkward feelings such as the ones mentioned.

$$tEDA < \; Med\; tEDA$$
$$T < \; Med\; T$$
$$TICS > \; Med\; TICS \tag{6.9}$$

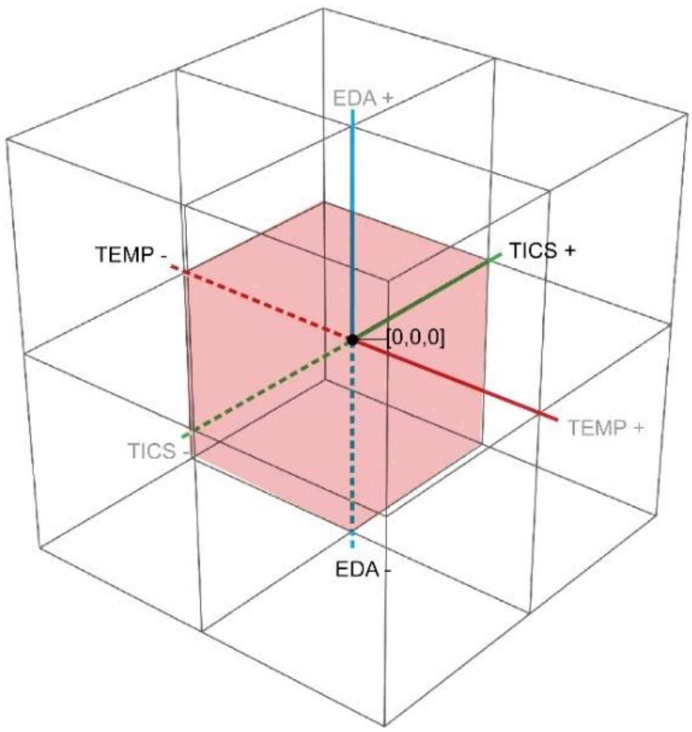


Figure 6. 13. Quadrant VIII (QVIII) in the 3D Mood Box.

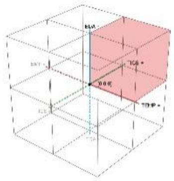
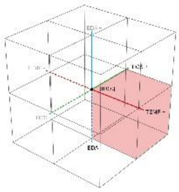
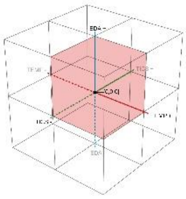
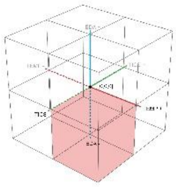
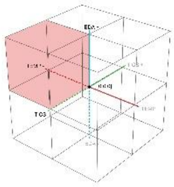
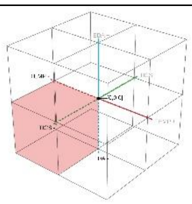
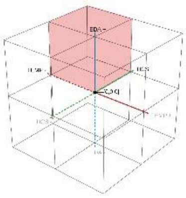
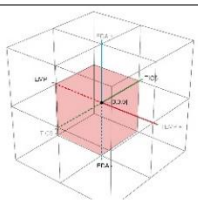
Location of the quadrant	Quadrant	Emotion/Mood	Combination of data
	QI	Excitement Joy	$tEDA > Med\ tEDA$ $T > Med\ T$ $TICS > Med\ TICS$
	QII	Contentment Pleasure Interest	$tEDA < Med\ tEDA$ $T > Med\ T$ $TICS > Med\ TICS$
	QIII	Happiness Amusement	$tEDA > Med\ tEDA$ $T > Med\ T$ $TICS < Med\ TICS$
	QIV	Relaxation Relief	$tEDA < Med\ tEDA$ $T > Med\ T$ $TICS < Med\ TICS$
	QV	Alertness Concentration Mental workload	$tEDA < Med\ tEDA$ $T < Med\ T$ $TICS < Med\ TICS$
	QVI	Distraction	$tEDA < Med\ tEDA$ $T < Med\ T$ $TICS < Med\ TICS$
	QVII	Anxiety Stress Anger Overstimulation	$tEDA > Med\ tEDA$ $T < Med\ T$ $TICS > Med\ TICS$
	QVIII	Frustration Annoyance Sadness Tiredness	$tEDA < Med\ tEDA$ $T < Med\ T$ $TICS > Med\ TICS$

Figure 6. 14 After collecting information about the variations of the physiological signals could represent in terms of emotions and feelings to the participants, and its correspondence to the different quadrants of the 3D Mood Box, as shown in pages 219 to 226, a table summarising all the associations was created (Figure 6.14). Table 6.14 summarises the meaning of every quadrant of the 3D Mood Box and shows the positive or negative valence of the feelings associated to every quadrant. Boxes shaded in Green indicate positive emotions, boxes shaded in Yellow indicate neutral feelings and boxes shaded in Red indicate negative feelings.

To sum up, when considering a bespoke design for each participant, the combination of data should lay around the quadrants I to IV, which show positive feelings. In situations in which mental workload or high concentration might be required, values around quadrant V would be appropriate. Results around the quadrants VI to VIII should be avoided given that these quadrants present negative feelings that can be detrimental such as fear and anxiety or undesirable feelings for high cognitive demanding tasks such as distraction.

6.6. Visualisation: the ***metaball*****s**

Every complete combination of data from each light exposure created a point. According to the coordinates of each point, a point was located in the corresponding quadrant, pointing out a possible group of emotions linked to the participant under certain light conditions. Therefore, it could be suggested that the participant felt the particular or similar emotions associated with the quadrant the point is located during the period this data was collected. Again, it is essential to emphasise that the feelings associated with every quadrant do not indicate absolute emotions, but the emotional tendency of the participant.

Hence, each point determines the possible emotions that the participant might have felt during one light exposure. Consistency of the results could indicate likely tendencies regarding the colour or the light, and this information could be used for bespoke design solutions. However, the sample of this case study was not significant enough.

A small sample, like the one obtained (13 days approximately), will convey the impression of the range of emotions the participant experienced under certain light conditions. This sample also helped to identify days in particular when the participant did not perform as usual to investigate the motives which could provoke the anomaly. A small change in the routine can alter the behaviour of young people affected by severe autism. These special days, showing a different pattern, seem evident once they are compared with all the other points.

After the different data-sets (points) were included in the three-dimensional space, a sphere was linked to each point to help a proper visualisation. These spheres are called *metaballs*.

The size of each *metaball* is relative to the proximity of the other *metaballs* with which they are compared. If the results are consistent and the points lie on the same part of the space or close, the *metaballs* will tend to merge, and this would indicate consistency.

A metaball is a sphere centred on a centroid which is the data point for the associated dimension obtained in the experiment. A metaball is given a set, starting, dimension, which is then modified about neighbouring metaballs. If a metaball can merge without further adaptation, it can be considered to be significant and consistent with the datapoint it represents. If the diameter of the metaball needs to be increased in order to merge with another, then its individual significance might decrease but its supradimensional significance might increase. The smaller the metaball is when it can merge, the more significant and consistent are the results. Sometimes, the metaballs are located far apart and need to be larger, in order to merge with others, indicating that the results differ and are less consistent.

Consequently, different multiplier factors for the size of the metaball are applied as needed. The different multiplier factors used were 1, 1.5, 2, 2.5, 3, 3.5, 4 and +4.5. The larger the multiplier factors, the bigger the *metaball*s. As the metaballs coalesce, they create volumes with different shapes and dimensions, and these show different patterns of behaviour regarding the different light factors.

A compact volume with a small *metaball* indicates that the different data-sets are close, and, for instance, are consistent and that the probability of feeling the same emotion under the same conditions might be higher. On the contrary, the further apart the *metaball*s are; the more expanded and divided is the volume. That might indicate that the emotions were less consistent and, thus, less predictable.

Based on the factors applied to each psychological range of values obtained to create a balanced 3D Mood Box, the more compressed the volume, the more consistent the results are. Metaballs which coalesce with a multiplier factor of 1.5 or less are considered to show consistent results. The higher the multiplier factor needed to merge the *metaball*s, the less consistent the results are. If the shape expands around many quadrants and/or is not compact, the less consistent are the results and, for instance, the mood cannot be predictable and suitable for specific purposes. The location of the volume(s) created by the accumulation of metaballs within the box indicates the associated quadrant and, thus, the likely sort of feelings of the participant. The different shapes obtained under different light conditions also inform about the different influence of the different types of light on the mood of the participants. If compared these shapes between participants, the shapes would highlight the particular way of perceiving the light (or any other architectural factor) of each individual and the different impact of the different types of light might have.

While this method was designed to understand the possible emotions felt under different light conditions, this three-dimensional model could also be used to show the influence of any other architectural factor has on the participant. Nevertheless, as indicated before, it might be necessary for a more significant sample.

To sum up, the three-dimensional interpretation of the data (3D Mood Box) can inform in many ways. First, this space helps to identify and understand the different emotions from any participant. Secondly, it is a tool that informs deeply without the need of using invasive devices or personal tools such as self-report questionnaires. Third, this 3D symbolisation can be used not only to study the influence of the light on people's mood but also to study the influence of many different architectonic features. Fourth, this kind of symbolisation is a tool to emphasise and show not only the differences in perception of specific features of the environment and emphasise the differences and similarities in perception between the participants, but also to show the idiosyncrasy of every participant.

This model of symbolisation and interpretation of the emotions was coded in Grasshopper.

6.7. Example:

The following example will show the rationale of the method and how it is put into practice introducing the data in the 3D Mood Box for later analysis.

To explain this process, the particular example of Participant F will be used to show how their mood registered under Yellow conditions and the steps which led to the mood interpretation. This example presents a clear and simple case to aid understanding and stands as a reference for how the process was undertaken in all the other cases in this research.

1. **The creation and introduction of the dataset in the system:**

   The first step is to gather all the data collected from each participant during the study concerning Tonic EDA, Temperature and Tics under all light conditions and to set the data in an Excel spreadsheet. Every participant will have a dataset which is individual and unique to them.

   The Excel spreadsheet is composed of five columns and as many rows as the number of light exposures recorded during the case study for the participant. The five columns correspond to (1) the day when the data was collected, (2) the colour of the light exposure, (3) the level of tonic EDA during the light exposure, (4) the temperature of the tip of the nose and (5) the rate per minute of tics during the light exposure (see Figure 6.15).

DAY	COLOUR	tEDA	Temp	Tics
2	W	0.420	35.45	2.45
2	B	0.155	35.4	10.98
2	G	0.384	35.57	6.16
3	Y	0.614	36.63	1.5
3	F	0.248	36.69	5
3	B	0.088	36.68	5.72
4	F	0.351	34.95	11.2
4	R	0.166	35.413	8.55
4	W	0.252	34.85	2.55
5	F	0.431	36.77	5.83
5	R	0.129	36.62	3.23
7	B	0.221	36.54	3.78
7	W	0.166	36.78	2.15
7	G	0.345	36.91	4.59
8	Y	0.328	35.19	2.1
8	F	0.558	35.99	3.04
8	R	0.631	36.05	1.36
9	G	0.318	37.35	2.52
9	R	0.492	36.8	3
9	Y	0.335	37.055	2.52
10	R	0.246	36.74	3.45
10	Y	0.468	36.8	4.8
10	B	0.511	37.09	2.04
11	W	0.150	36.93	2.38
11	G	0.306	37.29	5.16
11	F	0.379	37.52	5.985
12	G	0.105	36.481	0.52
12	W	0.352	36.67	1.2
12	F	0.349	36.85	0.78
13	R	0.048	36.47	1.44
13	B	0.159	36.64	0.2
13	W	0.475	36.87	0.888
14	W	0.086	37.03	4.8
14	B	0.089	37.05	1.68
14	G	0.233	37.09	1.8

Figure 6. 15. All the data collected for Participant F during the case study.

2. The creation of the origin point based on the specific dataset:

As mentioned in Section 6.3, the combination of the values of tEDA, Temperature and Tics for every day/session can indicate certain emotions the participant might feel during a specific moment. Therefore, the table obtained in the first step (Figure 6.15) contains all the information necessary to know all the possible emotions that Participant F felt during the case study. In other words, every row informs about the emotional state of the participant under the specified light exposure. However, these emotions are relative to an 'origin point' which is associated with and unique to each participant (see Section 6.2). All the emotions that result from the table (Figure 6.15) compose the range of emotions that the participant experienced during the case study.

In order to know under which situations the participant felt more relaxed, more excited or more stressed, the data has to be introduced into the 3D Mood Box (which is described in Section 6.3 and 6.4). First, it is crucial to obtain the origin point (Equation 6.1). As mentioned in Section 6.2, the coordinates of the origin point are the Median of every kind of data. In this example, the origin point is given by the three coordinates shown in Figure 6.16.

tEDA	Temp	Tics
0.318	36.690	2.550

Figure 6. 16. Coordinates of the origin point for Participant F obtained calculating the Median of tonic EDA, Temperature of the tip of the nose and the rate per minute of tics.

3. Locating the points in the 3D Mood Box:

Once the origin point is calculated, the three dimensions (tEDA, Temp. and Tics) create a virtual box composed by all the data obtained with their correspondent quadrants set around this origin point (see Figure 6.17). So the box has proper dimensions to expand the metaballs accordingly in all three directions, normalised tEDA values need to be multiplied by 20, temperature values need to be multiplied by 4, and RPM of tics values need to be multiplied by 1.

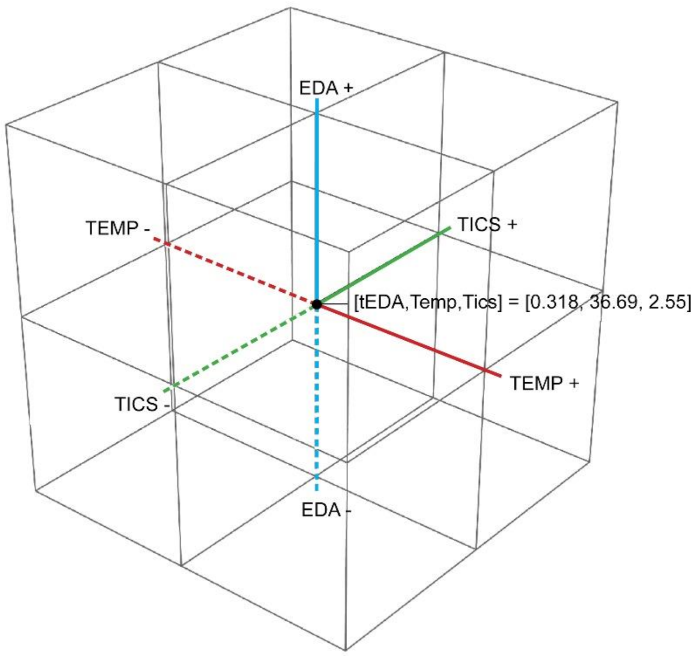


Figure 6. 17. 3D Mood Box created for Participant F.

Once the 3D Mood Box for Participant F is created, it is the moment to introduce the data points to study. For this example, the points to introduce are the ones obtained under Yellow light conditions (see Figure 6.18).

DAY	COLOUR	tEDA	Temp	Tics
2	W	0.420	35.45	2.45
2	B	0.155	35.4	10.98
2	G	0.384	35.57	6.16
3	Y	0.614	36.63	1.5
3	F	0.248	36.69	5
3	B	0.088	36.68	5.72
4	F	0.351	34.95	11.2
4	R	0.166	35.413	8.55
4	W	0.252	34.85	2.55
5	F	0.431	36.77	5.83
5	R	0.129	36.62	3.23
7	B	0.221	36.54	3.78
7	W	0.166	36.78	2.15
7	G	0.345	36.91	4.59
8	Y	0.328	35.19	2.1
8	F	0.558	35.99	3.04
8	R	0.631	36.05	1.36
9	G	0.318	37.35	2.52
9	R	0.492	36.8	3
9	Y	0.335	37.055	2.52
10	R	0.246	36.74	3.45
10	Y	0.468	36.8	4.8
10	B	0.511	37.09	2.04
11	W	0.150	36.93	2.38
11	G	0.306	37.29	5.16
11	F	0.379	37.52	5.985
12	G	0.105	36.481	0.52
12	W	0.352	36.67	1.2
12	F	0.349	36.85	0.78
13	R	0.048	36.47	1.44
13	B	0.159	36.64	0.2
13	W	0.475	36.87	0.888
14	W	0.086	37.03	4.8
14	B	0.089	37.05	1.68
14	G	0.233	37.09	1.8

Figure 6. 18. All the data collected for Participant F during the case study, with the Yellow exposures highlighted.

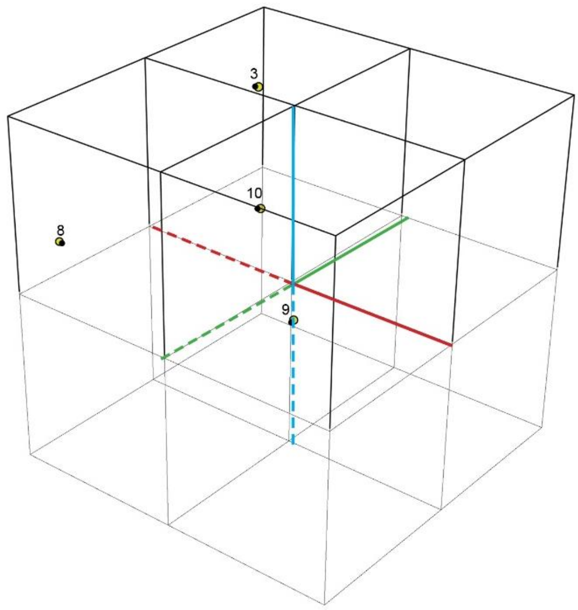


Figure 6. 19. Different points of data obtained under Yellow conditions located in the 3D Mood Box of Participant F.

4. Expanding the points physically in the 3D Mood Box – creating the metaballs:

The points shown in Figure 6.19 comprise points in a multidimensional space, where different units of measurement determine each axis. In order to extract the meaning behind the singular situation (e.g. the mood) that they describe in this case, it is necessary to understand how the position of points might constitute a more robust interpretation of the mood. One aspect of this is the position of the points in the three-dimensional space (as shown in Figure 6.19); another aspect is the extent to which these points in space relate to each other – not in mathematical terms because they are non-commensurate, but in a spatial – architectural – sense as a combined entity which could describe the sense of meaning – in this case, of a mood.

The question is then one of how to represent the fact that these 'points', collectively, represent a single, combined, meaning. To achieve this, the points are considered as being architectural, rather than abstract, points in space, and thus their physical size could be expanded physically until they merge with each other to form the single entity. Therefore, the points need to expand physically, from being abstract dimensionless points to 3-dimensional physical points in the 3D Mood Box. As a baseline model, the decision was taken to treat the points as a small sphere with its centroid located at the specific point given by its coordinates, which could be expanded equally in all directions by increasing the spherical diameter so that they have the dimensionality of a sphere (see Figure 6.20).

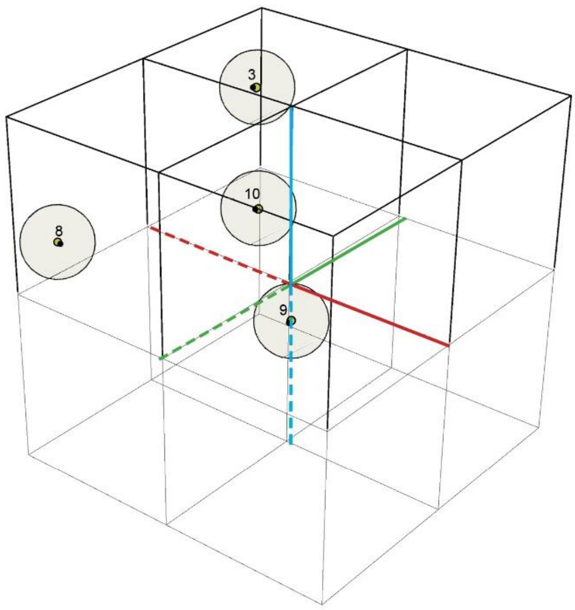


Figure 6. 20. The different points of data obtained under Yellow conditions located in the 3D Mood Box of Participant F expand physically for a better interpretation.

Then, as explained in Section 6.4, their individuality is tested by increasing the size of the sphere until it combines with another one so that the data points merge into one new shaped spatial figure. The spherical diameter of every point is increased equally until the resulting spheres coalesce into a single shape. The increasing of the diameters is stopped at the point where an infinitesimal reduction in the spherical diameter would cause the single shape to disintegrate. At this point, the shape obtained from the coalescence of the points is determined by both (1) the location of the constituent data points (because the centroids have remained in the same place in space) and (2) its definition as a single entity by the fact that it has become a single combined shape.

The ease with which two or more points can be combined into a single solid in this way is an indicator of the solidity of the idea. Thus the data points involved in the solid created might be considered to be representing the same mood. Therefore, if the diameter of the sphere increases by 1.5 times and the metaballs coalesce, it indicates that the points are close enough, so the data points are considered as being consistent and registering the same mood.

Figure 6.21 shows how, in the example of Participant F under Yellow, three out of the four data points coalesced when the spherical diameters were increased by a factor of 1.5. The metaballs associated with days 3, 10 and 9 show consistency enough to be considered the same mood, while the metaball associated with day 8 show different mood.

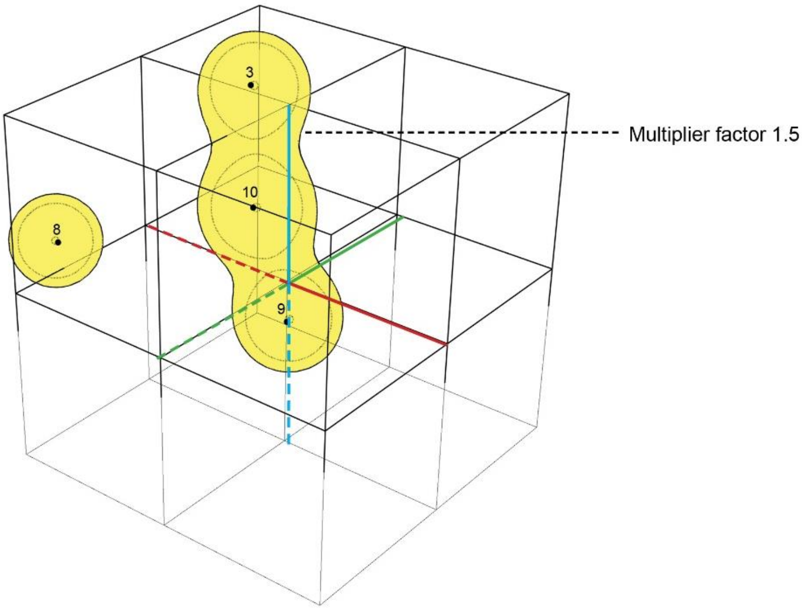


Figure 6. 21. The spheres associated with the points of data obtained under Yellow conditions located in the 3D Mood Box of Participant F show their consistency after increasing by 1.5.

The greater the factor needed to obtain coalescence, the less they can be considered to represent a single mood. If, for example, the diameter of the spheres needs to be increased more than by 1.5 times to coalesce and create a solid shape, that indicates that the relationship between the points is not consistent and the data can be considered to represent more than one different emotions (see Figure 6.22). The multiplier factor can, therefore, be considered to represent the consistency of the data points in expressing a mood – a smaller factor implies a greater consistency between the data points, and a larger factor a lesser consistency. In this case, until the spheres were not increased by 4.5, the metaballs did not coalesce. This fact showed no consistency and different mood between the solid shape created between days 3, 10 and 9 and the one obtained on day 8.

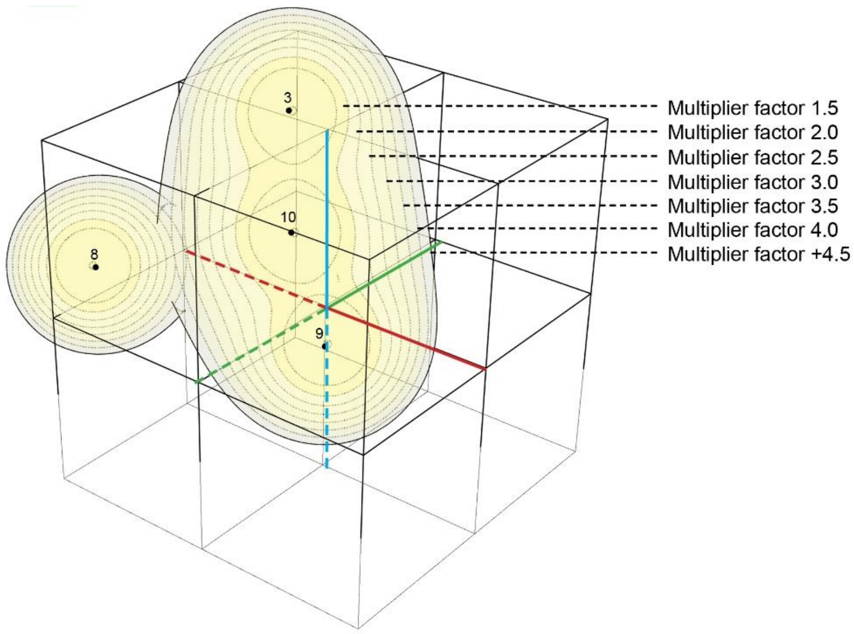


Figure 6. 22. Multiplier factor of 4.5 applied to merged the metaball associated to days 3, 10 and 9 with the metaball associated with day 8.

5. Interpreting the mood of the participant by identifying the location of the metaballs and her relative emotions:

After applying the multipliers to the spheres and after identifying the consistency or inconsistency between the different data points, the mood of the participant can be interpreted.

First of all, it is necessary to identify the quadrant where each data point is located. In this case: the metaball from day 3 is located in the intersection between quadrants III and V, the metaballs from days 9 and 10 are located in Quadrant III and the metaball from day 8 is located in quadrant V, close to the intersection with Quadrant VI.

Secondly, it is time to see where the consistent and coalesced 3D shape is located: the shape is located in quadrant III.

Therefore, as three out of four points coalesced in quadrant III, and considering the interpretation process explained in Section 6.3, it can be said that Participant F mainly felt high arousing positive feelings such as happiness and contentment under Yellow, thus a positive and good mood. These results suggest that applying Yellow when feeling stressed could improve this participant's mood. However, further research is necessary to confirm that the coloured light could improve negative feelings in extreme situations.

This method allows the possibility of identifying sessions when the participant did not behave as usual (e.g. day 8 compared with days 3, 9 and 10), and this suggests that it would be sensible to revise what happened during such sessions, in particular, that could have provoked the abnormality in the mood.

6.7. Other possible scenarios:

This example shows how the majority of the metaballs associated to the points coalesced in one quadrant, but results might not always be that clear. If more points are introduced in the 3D Mood Box, then more different scenarios might be created. Some of the possible scenarios can be:

1) **None of the metaballs coalesces after increasing the spheres by 1.5.** This could happen when, for example, the effect of the light is not consistent or weak. In these cases, on the one hand, it is interesting to see what multiplier factor is needed to coalesce and see how inconsistent the data points are. On the other hand, it is necessary to see if the data points expand around the positive quadrants, around the negative quadrants or in both. If the metaballs expand around all the quadrants, negative and positive, the outcomes from exposing the participant to this light might be very unpredictable and, sometimes, could lead to adverse outcomes.
2) **The metaballs coalesce in different but equally strong groups.** For example, from a sample of six data points, two points coalesced in one quadrant, two other points coalesce in another quadrant, and the last two points coalesce in another quadrant of the 3D Mood Box. In that case, results are not very consistent either, but it is worth paying attention to the positive or negative valence of the quadrants or the level of activation (tonic arousal) of the emotions.
3) **All the metaballs (or a vast majority) coalesce after increasing the spheres by 1.5, but the metaball created is not located in just one quadrant but different quadrants because it disperses around the box.** It is necessary to see if the data points expand around the positive quadrants, around the negative quadrants or in both. If the metaballs expand around all the quadrants, negative and positive, the outcomes from exposing the participant to this light might be very unpredictable and, sometimes, could lead to adverse outcomes.
4) **The metaballs coalesce in the intersection between negative and positive quadrants or in the origin point.** These metaballs could indicate that the mood registered might

be neutral or standard. In these cases, it is worth observing if there is a prevalence of positive or negative feelings.

Special attention has to be drawn to the isolated days which deviate from the norm, as seen in day 8 from the example presented. These isolated metaballs can provide information about events that happened on the day, that might be deemed inadvertent, that influenced the results and that could impact of their stress levels.

The points in the box associated with a particular colour light will show the emotional tendency the participant had under that particular light condition, so this prepares the data for eventual comparison to the other light conditions. In other words, considering the quadrants where the points are located, it will be possible to see if Participant F felt more relaxed or stressed under Yellow, for example, than under other lights.

This information will show us which light is more beneficial or induce better emotions than the others, regarding the participant studied, considering that the light that would induce positive emotions are the ones located in the positive quadrants (see Figure 6.11).

6.8. Chapter inference:

This chapter presented the rationale of the experimental method called 3D Mood Box, specially designed for this study and proposed to identify the emotional states of the participant under different light conditions.

To be able to understand in-depth the impact of the colour and source of the light in the mood of the four children with ASD who collaborated in the study, it was necessary to develop a new method that relied on objective data. Therefore, it was vital to collect physiological and behavioural information so the combination of the different kinds of data collected could complement each other and inform about the mood of the participants.

This chapter described the method 3D Mood Box, defined all its parts and discussed how it was created since the beginning. To interpret these data in relation to the mood of the participants, the data were analysed in relation to each other. Individually each can imply some characteristic of mood, and this is shown by the presence of data values in particular quadrants of the mood box. The question is then to see whether the three sets of data are consistent in suggesting a particular given mood. In order to explore this possibility, the data points were treated architecturally, as spheres, rather than points in space. This meant that the adjacency of data points could be explored physically to see when they might merge together – which would indicate that they are indicating the same outcome. Two ways of looking at this were then analysed. First, the amount by which the spheres had to be enlarged would indicate how consistent the combination would be – if they needed only a very small change in size, this suggests that the two spheres are indicating the same outcome, whereas if they require a large increase in size to coalesce, this would suggest that they are in fact not indicating the same outcome. Secondly, the location of the resulting combined shape in the context of the quadrants within the mood box indicates the mood that the data points are indicating. If the shape is contained entirely within one quadrant, that would suggest that this quadrant indicates the resulting mood, whereas if the shape straddles more than one quadrant, it would suggest that the mood might be better defined as a combination of mood types.

This chapter also described the different steps followed in interpreting the data and all the possible scenarios that can result from it, for a more straightforward interpretation of the data.

The next chapter presents the results of the mood under different light conditions of all the participants. In the first part of the chapter, it is described how the results will be displayed based on a template so the reader can understand better how the results obtained from a three-dimensional structure are displayed in two-dimensions for this thesis. The second part of the chapter will present the results obtained for every participant under different light conditions. The last part of the chapter will address questions such as how the source of the light (White and Fluorescent light) impacts on the mood of the participant and will also compare the results obtained about emotional states under different light conditions across participants so see similarities and differences in mood.

CHAPTER SEVEN - RESULTS FROM "3D MOOD BOX"

7.1. Introduction

As explained in Chapters Three and Four, the ultimate reason to monitor the physiological signals and analyse the behaviour of the participants under different light conditions, was to understand how the different colours and sources of light might impact on their mood.

In Chapter Six, there was described an innovative method proposed to understand the emotional states of the participants based on objective information. The method received the name of 3D Mood Box. 3D Mood Box consists of a three-dimensional structure where the three objective data collected from each participant (electrodermal activity, facial thermography and rate per minute of tics) were the three dimensions of the box. When intersecting in the origin point, these three dimensions create eight quadrants associated with different feelings that the participant might have felt during the light exposure. The combination of the three objective data under every light exposure creates a point which locates in a different part of the 3D Mood Box. The quadrant where the point is located indicates the relative emotional state of the participant under that light exposure.

Finally, there was an example of how the data introduced in the 3D Mood Box needs to be read and analysed.

This chapter presents the results obtained when introducing the data of the participants in the 3D Mood Box. First of all, there is an explanation about how the results will be displayed throughout the chapter. Second of all, the results obtained for each participant under different light conditions are presented. The daily analysis could shed light to certain results which deviate from the norm. For this reason, the 3D Mood Box obtained for each participant showing the data obtained by day, instead of by colour, as it will be presented in this chapter, is attached in Appendix I.

Every participant has a personal 3D Mood Box as it is created with the information gathered from him/her. It bears no relationship to any of the others. Three of the participants obtained enough information to obtain a bigger sample of metaballs and one of them had less information. As the study is about the method to identify responses, even though it was not possible to obtain as much information about one of the participants, his example was presented as well to observe the difference between enough data and insufficient data, and how to address these possible results in the future. As every 3D Mood Box is personal for each participant, the results from one participant do not affect any of the others. Participant J provided different and also very interesting data about his relationship with the colour of the light which was useful to understand in relation to the method, even though he was not able to communicate his feelings.

7.2. Reading the box through different layers:

7.2.1. The template:

For a proper understanding of the three-dimension visualisation regarding the influence of every light exposure on every participant, the data collected from the different sessions of every participant is displayed, by colours, in four different images (three projections (A, B, C) and a three-dimensional image (D)) and a table (E).

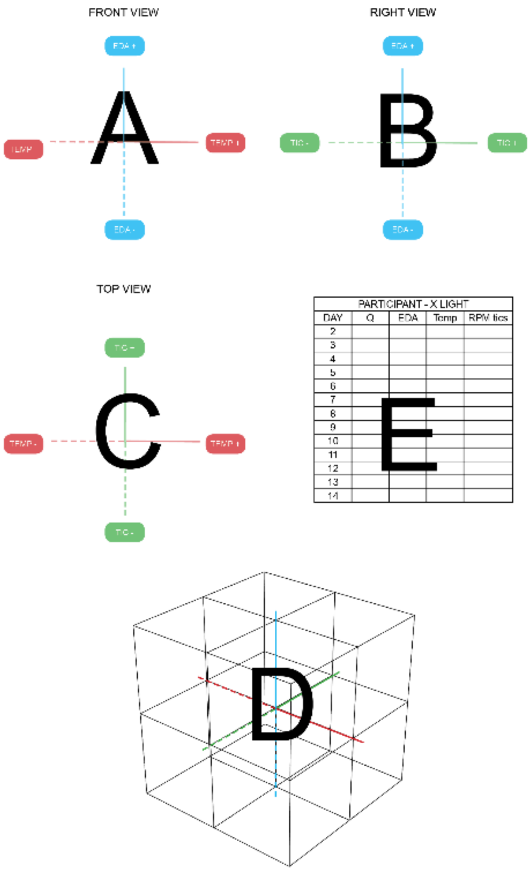


Figure 7. 1. Template used to show the data collected from the different sessions of every participant in the 3D Mood Box.

7.2.2. The projections:

To easily understand the data of the box, the box has to be dissected into different 2D projections that complement each other. The first three images displayed correspond to these three projections of the box: Front view (A), Right View (B) and Top View (C). These views facilitate the comprehension of the location of every dataset included in the three-dimensional space indicating the values of the physiological signals and the quadrants in which they are located.

The first image, Front View (A), is a two-dimensional view of the values of Tonic EDA and Temperature of the tip of the nose, associated with every dataset under every light exposure. On its right, the Right View (B) shows the values of Tonic EDA and RPM of tics associated with every dataset under every light exposure. Below the Front View, the Top View (C) shows the values of RPM of tics and Temperature of the tip of the nose associated with every dataset under every light exposure. Every projection shows the same information but from different points of view. Figure 7.2 shows the three projections of the 3D Mood Box as will be shown during this chapter. These projections also inform about the quadrants that compose the projections.

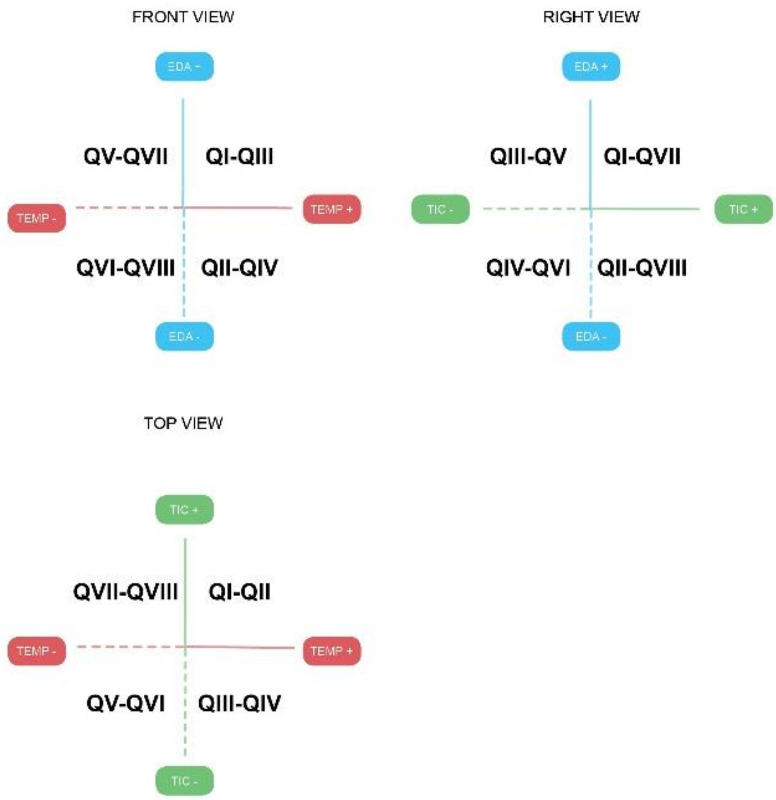


Figure 7. 2.The three two-dimensional projections providing the same information from the 3D Mood box, but in a more polished appearance for an easier interpretation of the data.

In order to aid understanding, every physiological signal has a different colour associated with it: the axis from Tonic EDA is blue, the axis from Temperature is red, and the axis from TICS is green. The axis which contains values higher than the Median is represented with a continuous line, while the axis which contains values lesser than the Median is represented with a dotted line. This same symbolisation is applied to the three-dimension view (D).

7.2.3. Three-dimension image – the axonometry:

The three projections correspond to three different points of view of the three-dimensional image. The different points of view correlated to the box are shown in Figure 7.3. This image shows which part of the box represents each two-dimensional projection explained in Figure 7.2: Orange facets represent Front View (A), yellow facets represent Right View (B) and pink facets represent Top View (C).

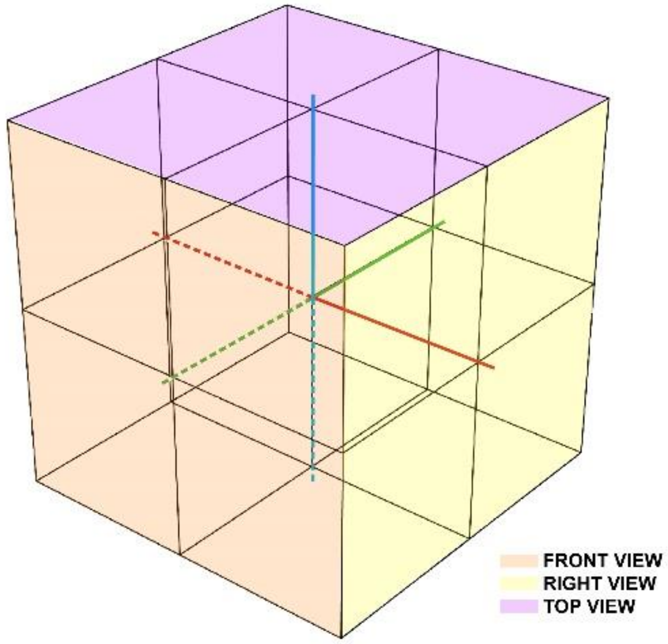


Figure 7. 3. Three-dimensional image and the three two-dimensional projections associated to it.

7.2.4. The table:

The table (E) which accompanies the images (see Figure 7.1) shows all the values of the different physiological signals obtained under the different light exposures for one participant and also shown in the images.

The table contains the day of the sessions in numerical form – which also appear linked to every metaball in the projections and the 3D image of the 3D Mood Box -, and the qualitative database composed by values of Tonic EDA (tEDA), the temperature of the tip of the nose (Temp), the rate per minute of tics (RPM tics) and the quadrant or quadrants (Q) associated with the combination of the three previous values for each light exposure.

7.2.6. How to read the quadrants on the images?

Every quadrant has a set of emotions associated, as explained in Section 6.3 from Chapter Six. These emotions can be positive, negative or neutral (alertness and mental workload). The division of the box into positive, negative and neutral quadrants is shown in Figure 7.4.:

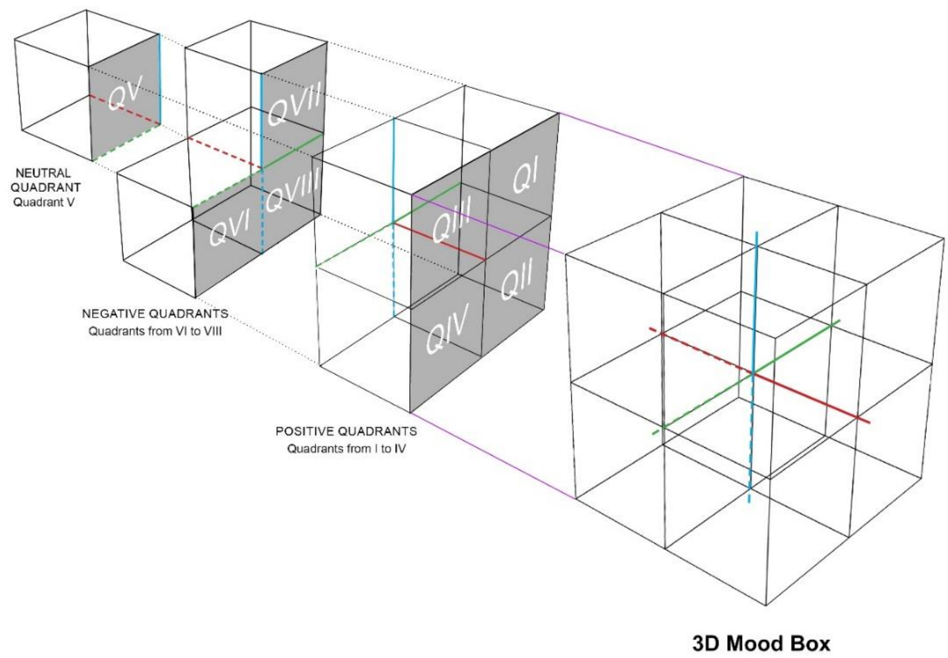


Figure 7. 4. Template of the three-dimensional image decomposed into the positive, negative and neutral quadrants.

7.2.7. What does the information in the box show?

The reason why the box was created was to combine the three physiological signals and see which emotion would prevail under a particular light condition.

In order to answer this question, the matter of interest is to know where the *metaballs* are located and identify the associated quadrant, and the emotion that the participant mainly felt under certain light conditions. As mentioned in Chapter Six, the quadrants are virtual infinite quadrants. A symbolic size has been assigned to the box to make the comparison of responses between different colours easier, so if the balls land inside the box or outside it, this is just a way to show the distance between the centre and origin point of the box and the point itself.

Once a quadrant is assigned to each *metaball*, it is interesting to know how many metaballs show similar results and, for instance, consistency. As previously mentioned, the metaballs which coalesce with a multiplier factor of 1.5 or less show consistent results. For this reason, the different multiplier factors are applied, and the behaviour of the metaballs are observed. The volume created with metaballs which coalesce with a 1.5 multiplier factor is considered as the prevalent mood if it contains half or more of the metaballs of each participant. The smaller the volume created, the more consistent and more predictable are the results.

It is also interesting to observe which metaballs do not coalesce under a multiplier factor of 1.5 and which multiplier factor would be needed in order to have all the metaballs coalesced. It should be pointed out that the bigger the multiplier factor needed to coalesce the spheres, the less consistent the results are.

As mentioned before, the emotion associated with every quadrant is not absolute, and the distance from the origin point also plays an important role. Moreover, it is interesting to see not only the type of emotion that the participant might be feeling but also whether the emotion is positive or negative. Sometimes, results do not specify a specific emotion, but results do show a positive or negative influence of the lighting conditions on the participant. Lighting conditions which induce positive feelings could be used in the built environment to improve their well-being.

Once the analysis of the individual influence that each colour has on the participant is done, results under different light conditions are compared. When comparing results under different light conditions, different factors are observed: the consistency of the results, the shape of the volume, the compactness of the volume and the feelings and positive/negative tendency of the feelings.

The comparison between participants can show the similarities and differences of the influence of the light on the emotions of the participants and how every participant has an individual and personal relationship with the environment.

The conclusions extracted could inform about the emotional influence that every light condition has on every participant, and this information can be used in the built environment to improve their emotional state and their well-being.

7.3. Results:

The results of the 3D Mood Box, showing the emotional states of every participant under every type of light, are next presented in this chapter, following the steps explained in Chapter Six. The figures illustrating these results will be displayed using the template previously explained in Section 7.2.

7.3.1. Participant F:

Participant F is a non-verbal young woman but has developed particular ways of communicating with her caregivers. These methods can be challenging most of the times and are not always easy to understand for the caregivers and relatives, not to mention other people who need to interact with her.

When she is confused or feels that she is not well understood, her levels of anxiety increase severely, causing an increase of tics and tantrums which impede her to carry on with the activities she is doing.

For this reason, this method was particularly useful to understand which environment was more suitable for her to boost her capabilities and improve her quality of life.

White:

Participant F was exposed to White, with a successful collection of the three complementary types of data, seven times. As explained in Chapter Six, it is essential to identify the quadrant were every dataset (point and metaball associated) is located. Therefore, the location of every session (or day) will be first identified and then the possible emotional states linked to the quadrant will be highlighted. It is crucial to remember that the emotions that will be mentioned are not absolute emotions but emotional tendencies based on all the data obtained from a participant and it has meaning when compared with results obtained under other types of lights. The emotions highlighted serve as a reference to know which kind of feelings the participant might have felt during the light exposure compared to other light conditions. The possible emotions associated to every quadrant (Q) are explained in Chapter Six and depend on the levels of arousal (tonic EDA), temperature of the tip of the nose and RPM of tics which are higher or lower than the median. The quantitative data associated to every session and influence the location of the metaballs in the 3D Mood Box is displayed in the Table.

The distribution of the points shown in Figure 7.5, referring to the 3D Mood Box of Participant F felt under the White was the following:

- On day 2, the *metaball* was located in Quadrant V or QV, showing feelings such as alertness and mental workload.
- Similarly, on day 12, the *metaball* was located in between QIII and QV, showing feelings between happiness and amusement and alertness and mental workload.

- On day 4, the *metaball* was located in QVIII, showing feelings such as relaxation and relief.
- Two out of seven times, on days 7 and 11, the metaballs were located in QIV, showing that the participant could have felt feelings such as relaxation and relief. However, on day 11, the *metaball* was located in between the QII and QIV, showing feelings between contentment, pleasure and interest and relaxation and relief.
- On day 13, the *metaball* was located in QI, showing feelings such as excitement.
- On day 14, the *metaball* is located in QII, showing feelings such as contentment, pleasure and interest.

After identifying the quadrant associated to every session, it is important to see how consistent the results are and how predictable are the emotions of the participant under a particular light condition. As explained in Chapter Six, if the metaballs coalesce when increasing the spheres by 1.5, results are consistent and the emotions can be predicted. If they do not coalesce when increasing the spheres by 1.5, results might not be consistent and cannot be predicted; therefore, environment design solutions might not be applied. The bigger the multiplier factor needed to coalesce the metaballs, the less consistent and more unpredictable are the emotional states of the participant under particular light condition. It is also crucial, especially when results are not consistent, to identify, at least, whether the feelings are positive or negative and their prevalence.

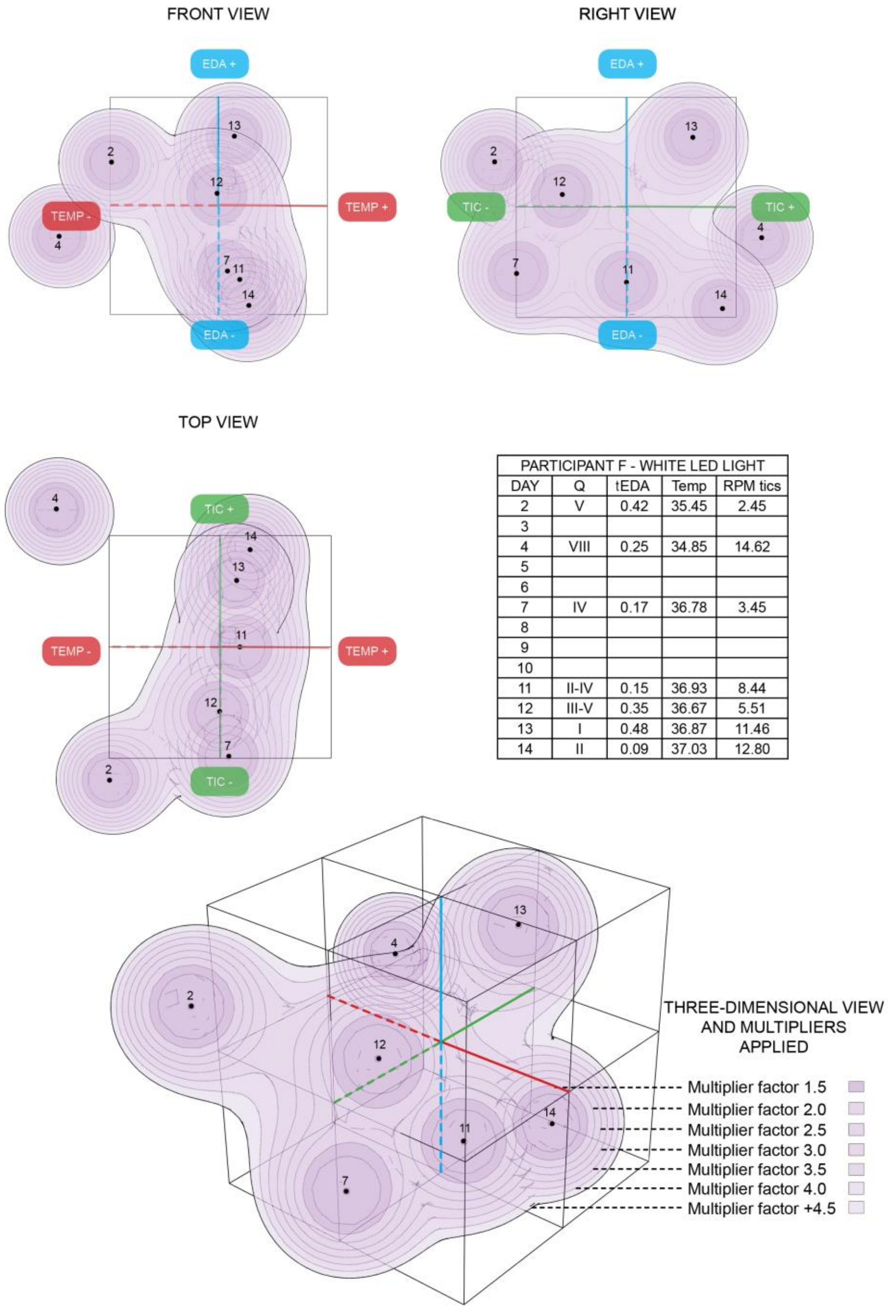
None of the observed datasets from Participant F obtained from White exposures merged under a multiplier factor of 1.5 or less. Therefore, no volume was created between the *metaball*s because all the spheres were dispersed in the 3D Mood Box.

The *metaball*s from days 7 and 12 needed a multiplier factor of 2.00 to merge. They coalesced between Quadrant III and Quadrant VI, indicating that the participant might feel feelings such as happiness, amusement, relaxation and relief under White light. If a multiplier factor of 2.5 is applied, these *metaball*s merged with *metaball*s from days 11 and 14, but higher multiplier factors were needed to merge with the rest of the datasets collected from the case study.

Thus, these results indicate that the results of the mood of Participant F under White might not be consistent and, the mood under White could not be predicted.

Overall, five out of seven days the feelings of Participant F observed under White were considered as positive feelings, one out of seven days the participant was mainly concentrated or alert, and only one day the participant felt negative emotions under the White light.

Consequently, results shown in Figure 7.5. indicate that even though it could not be possible to predict the feelings the participant could feel under White, the participant did feel mainly positive feelings under the White LED exposures.



PARTICIPANT F - WHITE LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2	V	0.42	35.45	2.45
3				
4	VIII	0.25	34.85	14.62
5				
6				
7	IV	0.17	36.78	3.45
8				
9				
10				
11	II-IV	0.15	36.93	8.44
12	III-V	0.35	36.67	5.51
13	I	0.48	36.87	11.46
14	II	0.09	37.03	12.80

Figure 7. 5. 3D Mood Box of Participant F under White conditions (displayed in colour purple for a better comprehension). This group of images presents the data from the physiological signals combined of Participant F under White LED light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table. Results are

Fluorescent light:

Participant F was exposed to Fluorescent light, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.6, referring to the 3D Mood Box of Participant F felt under Fluorescent light was the following:

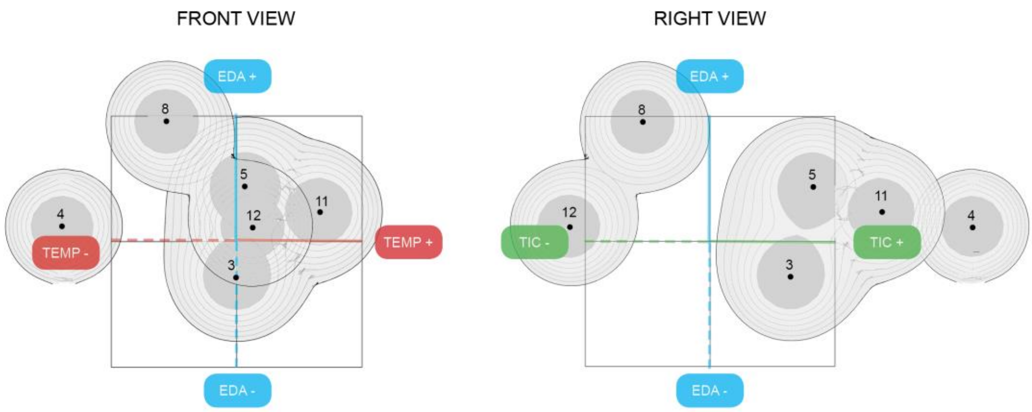
- On day 3, the *metaball* was located in between QII and QVIII, showing feelings between contentment, pleasure and interest and frustration, annoyance, sadness and tiredness. Results shown on day 3 under Fluorescent light might indicate that the feeling could be considered more neutral and standard, because it locates close to the origin point.
- On day 4, the *metaball* was located in QVII, showing feelings such as anxiety, stress, anger and overstimulation.
- Two out of six times, on days 5 and 11, the metaballs were located in QI, showing that the participant could have felt feelings such as excitement.
- On day 8, the *metaball* was located in QV, showing feelings such as alertness and mental workload.
- On day 12, the *metaball* was located in QIII, showing feelings such as happiness and amusement.

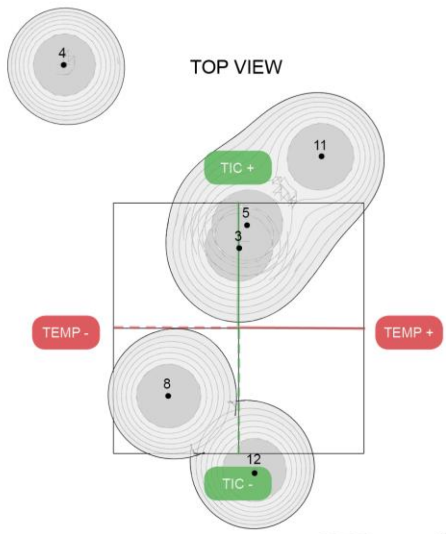
None of the observed datasets from Participant F obtained from Fluorescent light exposures merged under a multiplier factor of 1.5 or less. Therefore, no volume was created between the *metaball*s because all the spheres were dispersed in the 3D Mood Box.

The *metaball*s from days 3, 5 and 11 need a multiplier factor of 2.00 to merge. They coalesced in Quadrant I, indicating that the participant might feel feelings such as excitement and joy under Fluorescent Light. This volume would coalesce with the rest of the results if a multiplier factor greater than 4.0 were applied.

Therefore, these results indicate that the mood of Participant F under Fluorescent light might not be consistent and, thus, no particular mood specific to Fluorescent light could be predicted.

Overall, three out of six days the feelings of Participant F observed under Fluorescent light were considered as positive feelings, one day out of six results can be considered neutral, one day the participant was mainly concentrated, and one day the participant felt negative emotions under Fluorescent light. Consequently, results shown in Figure 7.6 indicate that the participant felt mainly positive feelings under Fluorescent light exposures.





PARTICIPANT F - FLUORESCENT LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3	II-VIII	0.25	36.69	11.65
4	VII	0.35	34.95	18.95
5	I	0.43	36.77	12.54
6				
7				
8	V	0.56	35.99	5.73
9				
10				
11	I	0.38	37.52	15.33
12	III	0.35	36.85	2.77
13				
14				

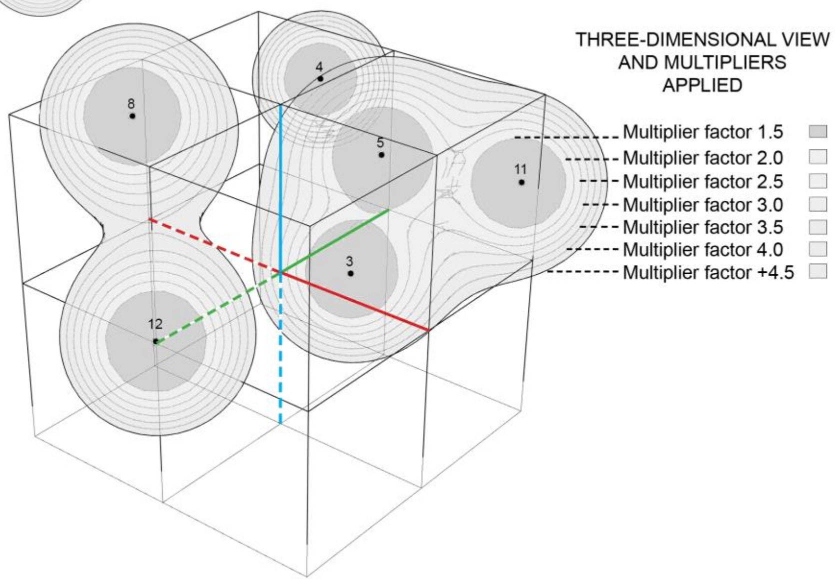


Figure 7. 6. 3D Mood Box of Participant F under Fluorescent light conditions (displayed in colour grey for a better comprehension). This group of images presents the data from the physiological signals combined of Participant F under Fluorescent light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Yellow:

Participant F was exposed to Yellow, with a successful collection of the three complementary types of data, four times. The distribution of the points shown in Figures 7.7, referring to the 3D Mood Box of Participant F felt under Yellow was the following:

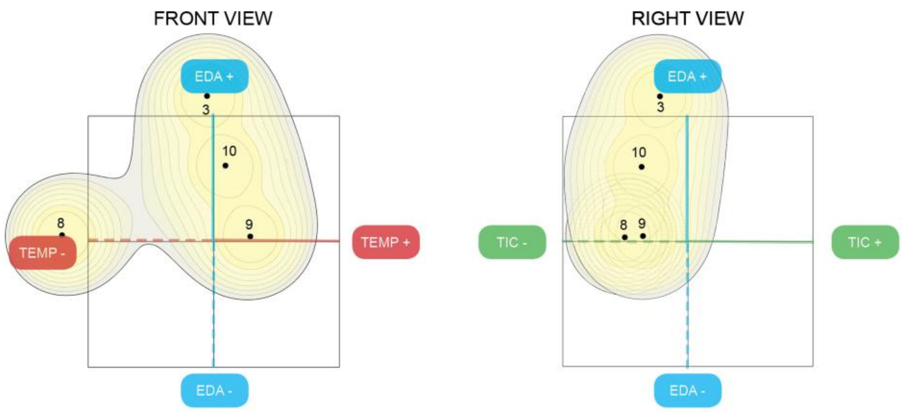
- Two out of four times, on days 9 and 10, the metaballs were located in QIII, showing that the participant could have felt feelings such as happiness and amusement.
- Two out of four times, on days 3 and 8, the *metaballs* were located in QV, showing feelings such as alertness and mental workload

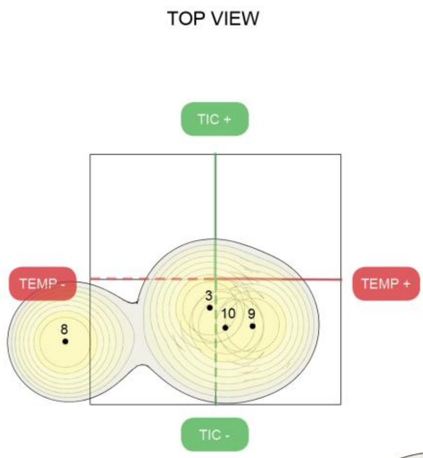
The datasets from days 3, 9 and 10 coalesced with a multiplier factor of 1.5, creating a volume located in Quadrant III, indicating that the predominant feeling that Participant F might feel under Yellow was happiness or amusement.

The *metaball*s from day 8 needed a multiplier factor higher of 4.00 to merge with other *metaball*s, indicating that Participant F experienced a different kind of feelings under Yellow on day 8. In this case, the participant might be concentrated.

The volume created with the 1.5 multiplier factor, composed by the majority of the datasets collected and which expanded in Quadrant III, indicated that the results observed under Yellow might be consistent. Therefore, these results might shed light on the mood of Participant F under Yellow. The mood might be predicted, and this information might be used for future purposes.

Overall, two out of four days the feelings of Participant F observed under Yellow were considered as positive feelings, only one day the participant was mainly concentrated, and only one day the participant felt negative emotions under Yellow. Consequently, results shown in Figure 7.7 indicate that the participant felt mainly positive feelings such as happiness under Yellow exposures.





PARTICIPANT F - YELLOW LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3	V	0.61	36.63	7.30
4				
5				
6				
7				
8	V	0.33	35.19	5.93
9	III	0.33	37.06	6.62
10	III	0.47	36.80	6.57
11				
12				
13				
14				

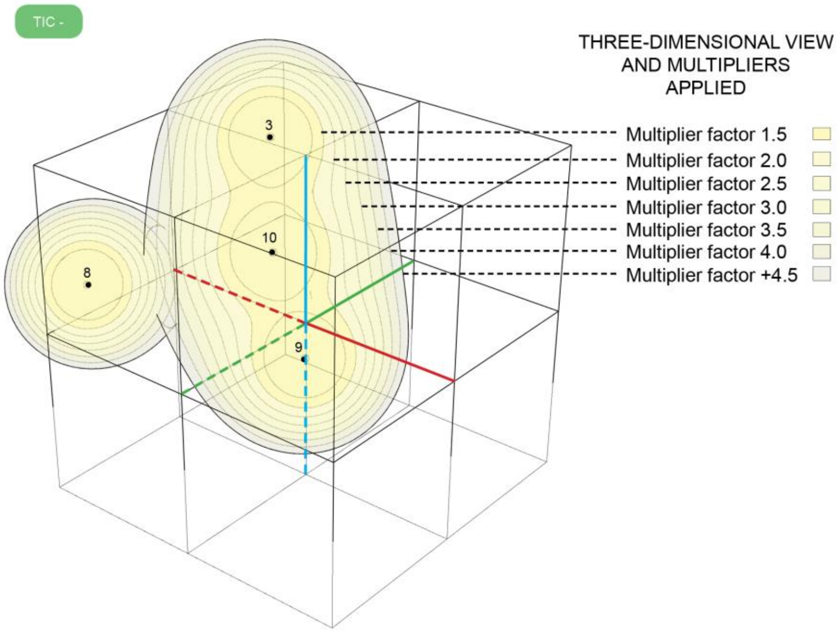


Figure 7. 7. 3D Mood Box of Participant F under Yellow light conditions (displayed in colour yellow for a better comprehension). This group of images presents the data from the physiological signals combined of Participant F under Yellow light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Green:

Participant F was exposed to Green, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.8, referring to the 3D Mood Box of Participant F felt under Green was the following:

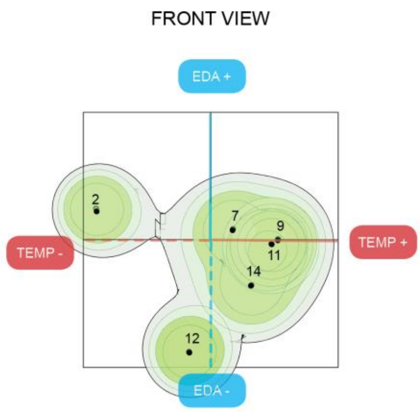
- Two out of six times, on days 7 and 9, the metaballs were located in QIII, showing that the participant could have felt feelings such as happiness and amusement.
- On day 2, the *metaball* was located in QV, showing feelings such as alertness and mental workload.
- On day 11, the *metaball* was located in QII, showing feelings such as contentment, pleasure and interest.
- On day 12, the *metaball* was located in QVI, showing feelings such as distraction.
- On day 14, the *metaball* was located in QIV, showing feelings such as relaxation and relief.

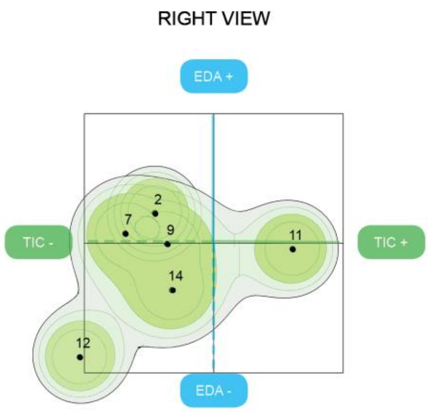
The datasets from days 7, 9 and 14 coalesced with a multiplier factor of 1.5, creating a volume located between Quadrant III and Quadrant IV, indicating that, half of the sessions, the predominant feelings that Participant F might feel under Green were happiness, amusement or relaxation and relief.

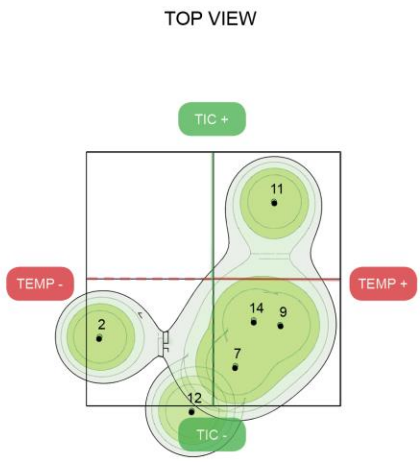
The *metaball*s from days 11 and 12 needed a multiplier factor higher of 2.00 to merge with the volume mentioned. The other *metaball*s coalesced with a 2.5 multiplier factor. These results indicate that Participant F experienced different kind of feelings under Green on days 2. In this case, the participant might be concentrated.

The volume created with the 1.5 multiplier factor, composed by half of the datasets collected, which expanded between Quadrant III and Quadrant IV, indicated that the results observed under Green might be consistent. Therefore, these results might shed light on the mood of Participant F under Green. The mood might be predicted, and this information might be used for future purposes.

Overall, four out of six days the feelings of Participant F observed under Green were considered as positive feelings, only one day the participant was mainly concentrated or alert and only one day the participant felt negative emotions under Green. Consequently, results shown in Figure 7.8 indicate that the participant felt mainly positive feelings such as happiness and relaxation under Green exposures.







PARTICIPANT F - GREEN LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2	V	0.38	35.57	6.16
3				
4				
5				
6				
7	III	0.34	36.91	5.01
8				
9	III	0.32	37.35	6.63
10				
11	II	0.31	37.29	11.50
12	VI	0.10	36.48	3.24
13				
14	IV	0.23	37.09	6.82

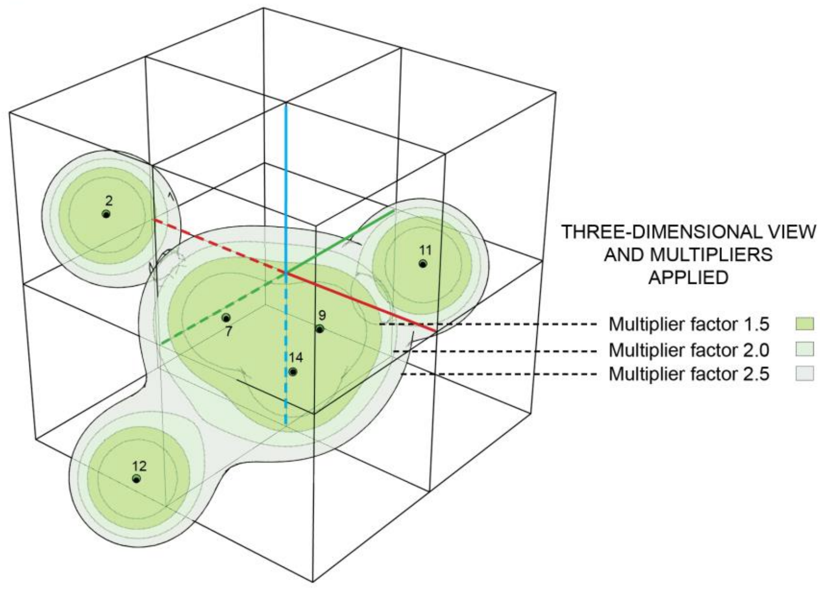


Figure 7. 8. 3D Mood Box of Participant F under Green light conditions (displayed in colour green for a better comprehension). This group of images presents the data from the physiological signals combined of Participant F under Green light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Red:

Participant F was exposed to Red, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.9, referring to the 3D Mood Box of Participant F felt under Red was the following:

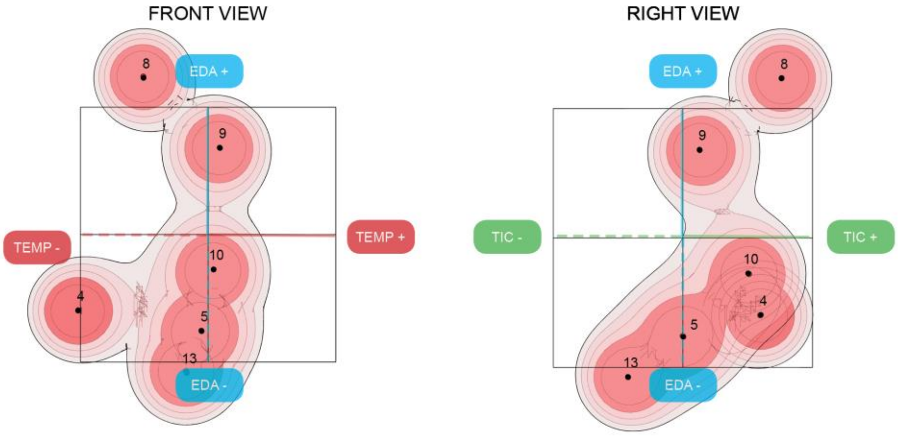
- Two out of six times, on days 5 and 13, the metaballs were located in QVI, showing that the participant could have felt feelings such as distraction. However, on day 5, the *metaball* was located between the QVI and QVIII, showing feelings between distraction and frustration, annoyance, sadness and tiredness.
- On day 4, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.
- On day 8, the *metaball* was located in QVII, showing feelings such as anxiety, stress, anger and overstimulation.
- On day 9, the *metaball* was located between the QI and QIII, showing feelings between excitement and happiness and amusement.
- On day 10, the *metaball* was located in QII, showing feelings such as excitement.

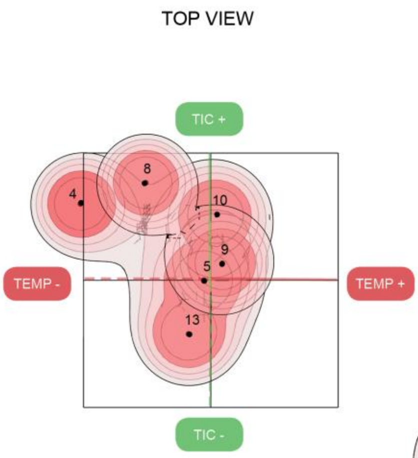
The datasets from days 5, 10 and 13 coalesced with a multiplier factor of 1.5, creating a volume located between Quadrant II and Quadrant VI, indicating that, half of the sessions, the predominant feeling that Participant F might feel under Red was pleasure, interest or/and distraction.

The *metaball*s from days 4, 8 and 9 needed a multiplier factor higher of 3.00 to merge with the volume mentioned. These results indicate that Participant F experienced a different kind of feelings under Red on these days.

The volume created with the 1.5 multiplier factor, composed by half of the datasets collected and which expanded between Quadrant II and Quadrant VI, indicated that the results observed under Red might be consistent. Therefore, these results might shed light on the mood of Participant F under Red. The mood might be predicted, and this information might be used for future purposes.

Overall, two out of six days the participant felt positive emotions and four out of six days the feelings of Participant F observed under Red were considered as negative feelings under Red. Consequently, results shown in Figure 7.9 indicate that the participant felt mainly negative feelings such as tiredness and annoyance under Red exposures.





PARTICIPANT F - RED LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4	VIII	0.17	35.41	11.45
5	VI-VIII	0.13	36.62	8.45
6				
7				
8	VII	0.63	36.05	12.28
9	I-III	0.49	36.80	9.11
10	II	0.25	36.74	11.02
11				
12				
13	VI	0.05	36.47	6.34
14				

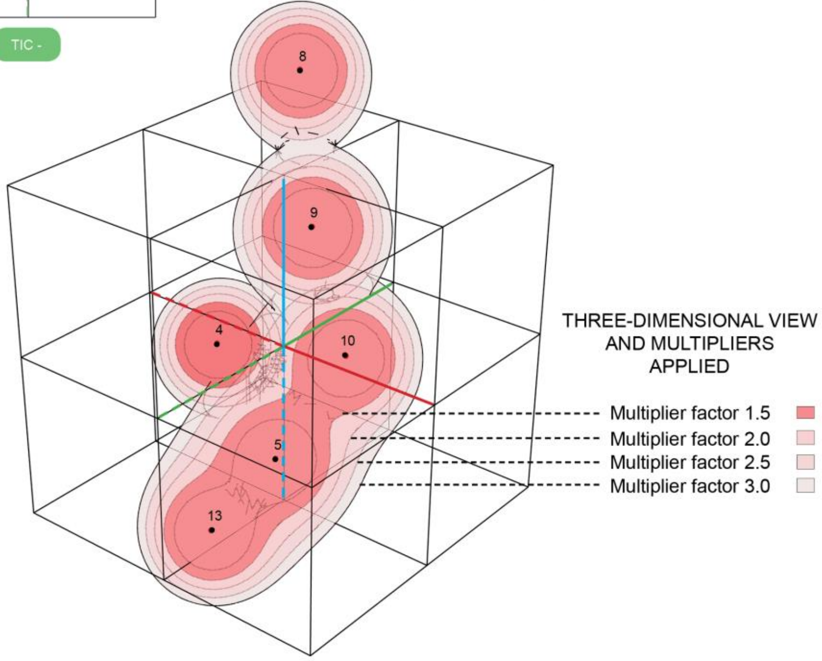


Figure 7. 9. 3D Mood Box of Participant F under Red light conditions (displayed in colour red for a better comprehension). This group of images presents the data from the physiological signals combined of Participant F under Red light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Blue:

Participant F was exposed to Blue, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.10, referring to the 3D Mood Box of Participant F felt under Blue was the following:

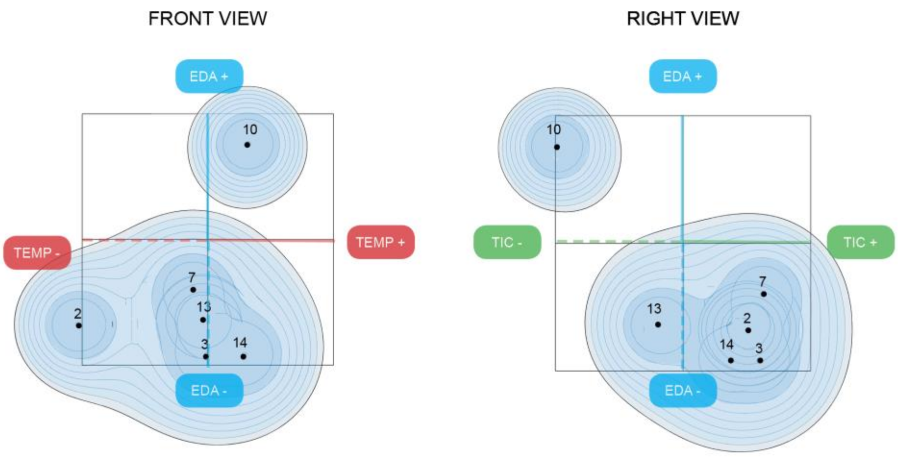
- Three out of six times, on days 2, 3 and 7, the metaballs were located in QVIII, showing that the participant could have felt feelings such as frustration, annoyance, sadness and tiredness.
- On day 10, the *metaball* was located in QIII, showing feelings such as happiness and amusement.
- On day 13, the *metaball* was located in QVI, showing feelings such as distraction.
- On day 14, the *metaball* was located between the QII, showing feelings such as excitement.

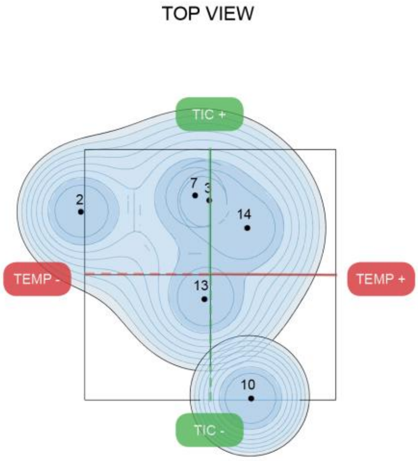
The datasets from days 3, 7, 13 and 14 coalesced with a multiplier factor of 1.5, creating a volume located between Quadrant II, Quadrant VI and Quadrant VIII, indicating that, the majority of the sessions, the predominant feelings that Participant F might feel under Blue were distraction, interest, annoyance and tiredness.

The *metaball* from day 2 needed a multiplier factor higher of 2.00 to merge with the volume mentioned. The *metaball* from day 10 needed a multiplier factor higher of 4.50 to merge with the volume mentioned. These results indicate that Participant F experienced a different kind of feelings under Blue on day 10, showing feelings such as happiness and amusement.

The volume created with the 1.5 multiplier factor, composed by the majority of the datasets collected and which expanded between Quadrant II, Quadrant VI and Quadrant VIII, indicated that the results observed under Blue might be consistent. Therefore, these results might shed light on the mood of Participant F under Blue. The mood might be predicted, and this information might be used for future purposes.

Overall, two out of six days the feelings of Participant F observed under Blue was considered as positive feelings, and four out of six days the results indicate that the participant felt negative emotions under Blue. Consequently, results shown in Figure 7.10 indicate that the participant felt mainly negative feelings such as annoyance and tiredness under Blue exposures.





PARTICIPANT F - BLUE LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2	VIII	0.15	35.40	10.98
3	VIII	0.09	36.68	11.42
4				
5				
6				
7	VIII	0.22	36.54	11.58
8				
9				
10	III	0.51	37.09	3.51
11				
12				
13	VI	0.16	36.64	7.47
14	II	0.09	37.05	10.30

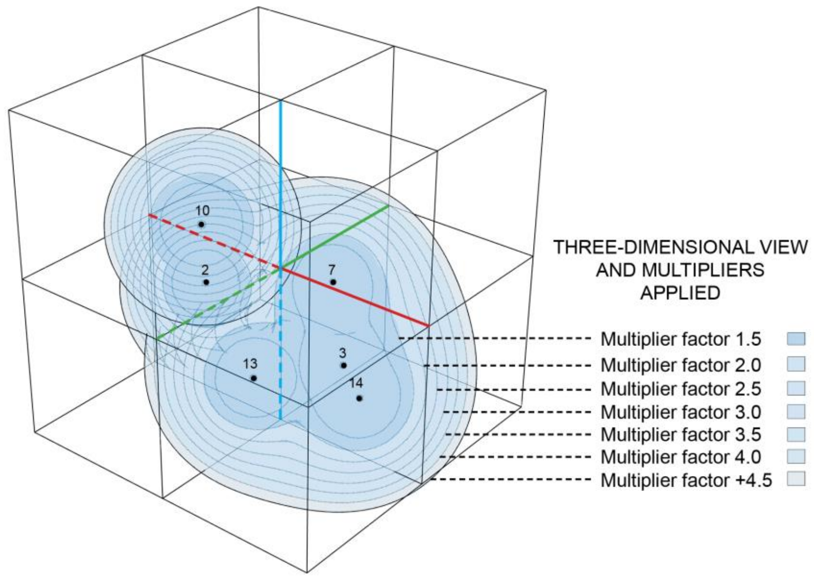


Figure 7. 10. 3D Mood Box of Participant F under Blue light conditions (displayed in colour blue for a better comprehension). This group of images presents the data from the physiological signals combined of Participant F under Blue light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Conclusions for Participant F:

The characteristics of the different volumes created under the different light conditions indicated that the different types of light do impact differently in the mood of Participant F.

Comparison between White and Fluorescent. The importance of the source of the light:

Figure 7.11 shows the results obtained from White LED exposures and Fluorescent light exposures for Participant F. Results indicate that the influence of the White, and the Fluorescent light affected the mood of Participant F in a similar manner.

Results of both cases show that the *metaballs* are dispersed and expand around all the quadrants and did not coalesce with a significant multiplier factor of 1.5. Even though there was no consistency showing particular feelings under these lights, indicating that the feelings cannot be predicted, there was a similar distribution of the *metaballs* around the positive and negative quadrants, and a prevalence of positive feelings under both lights.

These findings indicate that Participant F did not show a significant difference in the mood regarding the source of the light and that both lights, LED and Fluorescent, seem to induce similar mood in the participant.

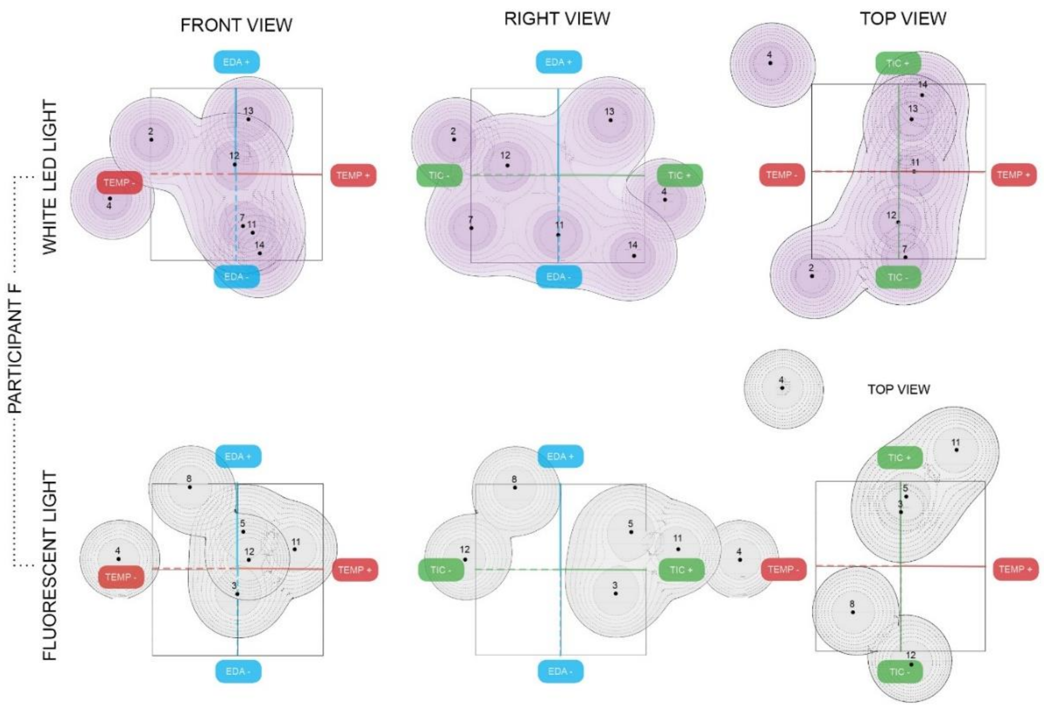


Figure 7. 11.3D Mood Box of Participant F under White and Fluorescent light conditions (displayed in colour purple and grey, respectively,). Every metaball is associated with a number, which indicates the day of the dataset was collected.

The influence of the colour of the light on the participant's mood:

Figure 7.12 shows the results obtained under different LED colour lights for Participant F. Results obtained under the different coloured LED lights are consistent and coalesced with a multiplier factor of 1.5 creating different volumes and shapes for every colour. These results indicate that every colour of the light could induce different feelings, and this information could be used in the environment to obtain different outcomes.

Results of Yellow and Green exposures show that these colours of the light seemed to induce positive feelings to Participant F. Yellow and Green seemed to stimulate feelings such as happiness and amusement from Quadrant III.

However, results also show that Participant F felt mainly negative feelings under Red and Blue exposures.

Considering the results mentioned, in order to improve the well-being and quality of life of Participant F in the environment, Yellow could be used to increase her happiness levels. Green could be the more suitable light to calm her if she were feeling stressed, and Red and Blue should be avoided as it might provoke annoyance and tiredness.

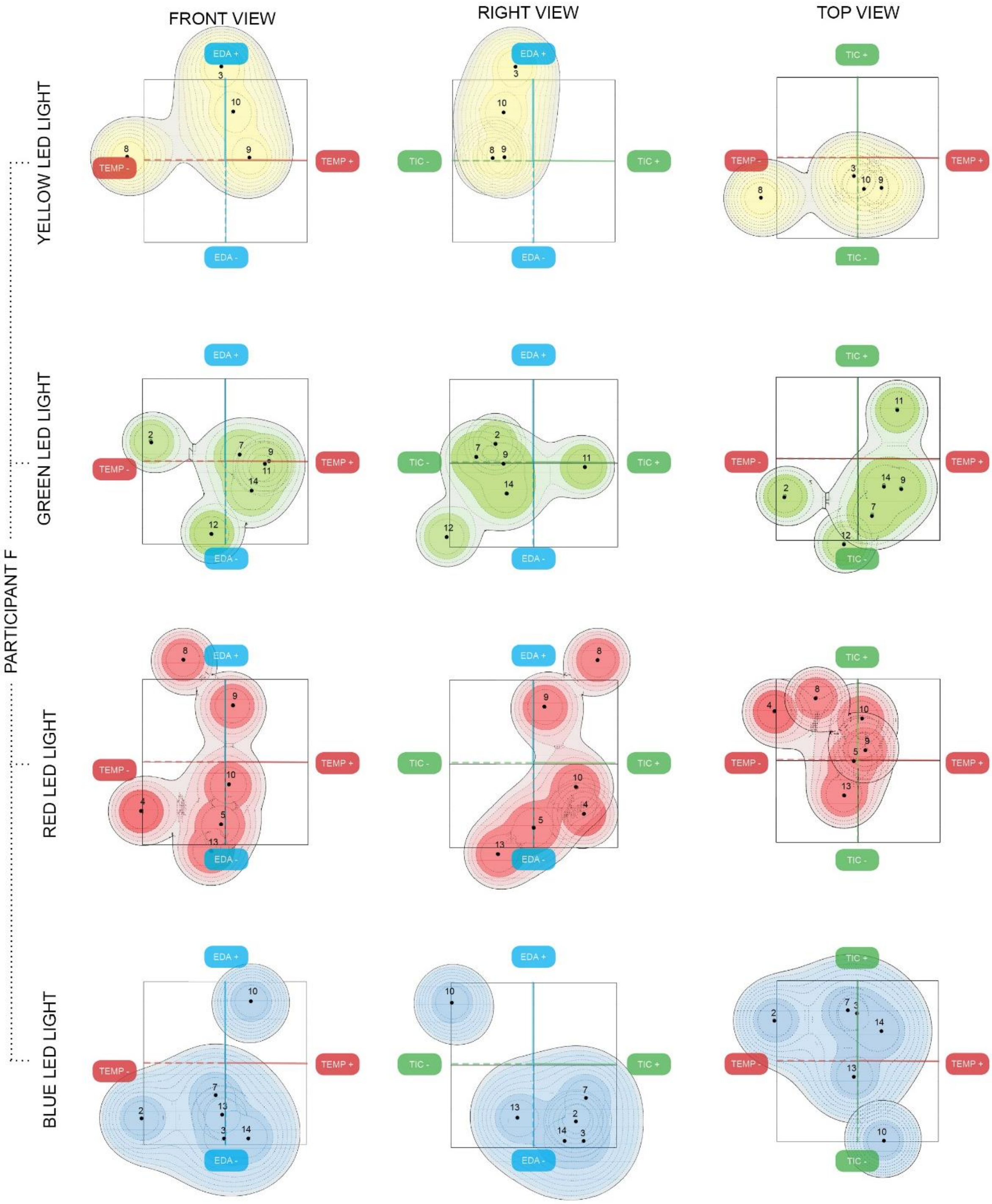


Figure 7. 12. 3D Mood Box of Participant F under Yellow, Green, Red and Blue conditions (displayed in colour yellow, green, Red and blue, respectively). Every metaball is associated with a number, which indicates the day of the dataset was collected.

7.3.2. Participant FX:

Participant FX is a very collaborative young man. His way to answer the questions the therapists asked him is by repeating words and simple sentences he has heard before in the school or TV, showing that his language is echolalic. Even though he can speak, he cannot create sentences or follow a complicated conversation.

He is an easy-going student, but small changes in routines affect him severely. When his levels of anxiety increase, he stops doing whatever he is doing, no matter what it is. Moreover, Participant FX suffers from incontinence — a condition which worsens when the levels of anxiety are elevated.

For these reasons, this method was particularly useful to understand which environment was more suitable for him to improve his quality of life and well-being.

White:

Participant FX was exposed to White, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.13, referring to the 3D Mood Box of Participant FX felt under White was the following:

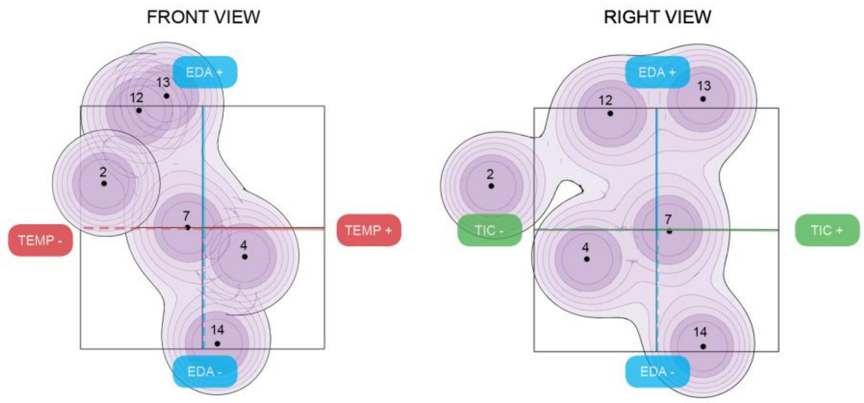
- Two out of six days, on days 2 and 12, the *metaballs* were located in QV, showing feelings such as alertness and mental workload.
- On day 4, the *metaball* was located in QIV, showing feelings such as relaxation and relief.
- On day 7, the *metaball* was located in between the QVII and QVIII, showing feelings between anxiety, stress, anger and overstimulation and frustration, annoyance, sadness and tiredness.
- Similarly, on day 13, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.
- On day 14, the *metaball* was located in QII, showing feelings such as contentment, pleasure and interest.

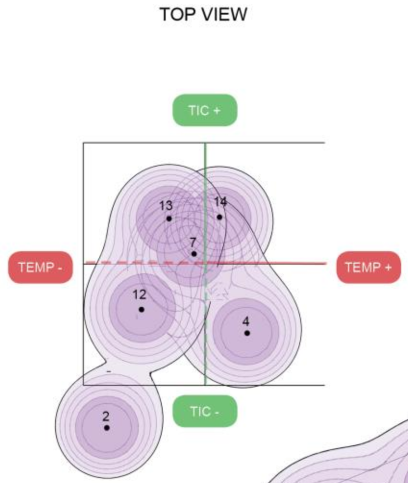
None of the observed datasets from Participant FX obtained from White exposures merged under a multiplier factor of 1.5 or less. Therefore, no volume was created between the *metaball*s because all the spheres were dispersed in the 3D Mood Box.

The *metaball*s needed a multiplier factor of 3.00 or more to merge.

Therefore, these results indicate, that the mood of Participant FX under White might not be consistent and, thus, the mood under White could not be predicted.

Overall, two out of six days the feelings of Participant FX observed under White were considered as positive feelings, two out of six days the participant felt mainly concentrated, and two out of six days the participant felt negative emotions under White light. Consequently, results shown in Figure 7.13 indicate that the participant felt many naturally different feelings under the White LED exposures.





PARTICIPANT FX - WHITE LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2	V	0.51	34.20	0.28
3				
4	IV	0.36	35.64	4.20
5				
6				
7	VII-VIII	0.42	35.06	7.56
8				
9				
10				
11				
12	V	0.66	34.56	5.15
13	VIII	0.69	34.84	8.97
14	II	0.18	35.36	8.93

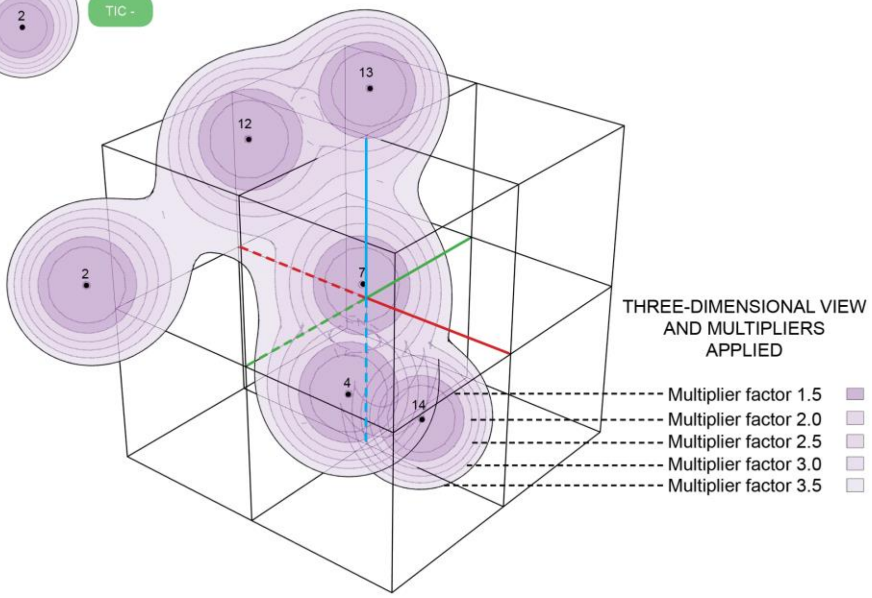


Figure 7. 13. 3D Mood Box of Participant FX under White conditions (displayed in colour purple for a better comprehension). This group of images presents the data from the physiological signals combined of Participant FX under White LED light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Fluorescent light:

Participant FX was exposed to Fluorescent light, with a successful collection of the three complementary types of data, five times. The distribution of the points shown in Figures 7.14, referring to the 3D Mood Box of Participant FX felt under Fluorescent light was the following:

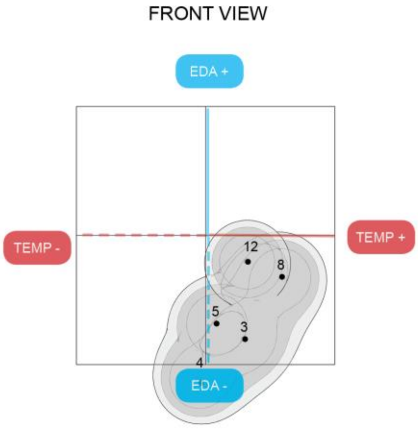
- Three out of five days, on days 3, 5 and 8, the *metaballs* were located in QII, showing feelings such as contentment, pleasure and interest.
- On day 4, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness, although it is extremely closed to QII (pleasure)
- On day 12, the *metaball* was located in QIV, showing feelings such as relaxation and relief.

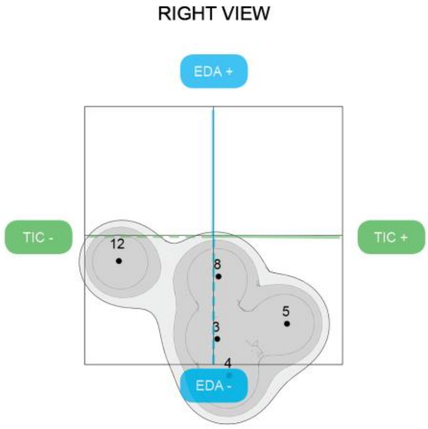
The datasets from days 3, 4, 5 and 8 coalesced with a multiplier factor of 1.5, creating a compacted volume located mainly in Quadrant II, indicating that, the majority of the sessions, the predominant feelings that Participant FX might feel under Fluorescent light were contentment, pleasure and interest.

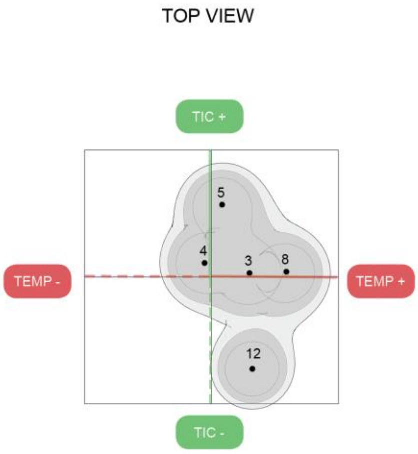
The *metaball* from day 12, however, needed a multiplier factor higher of 2.00 to merge with the volume mentioned. These results indicated that Participant FX experienced similar physiological feelings, under Fluorescent light.

The volume created with the 1.5 multiplier factor, composed by the majority of the datasets collected and which expanded in Quadrant II, indicated that the results observed under Fluorescent light might be consistent. Therefore, these results might shed light on the mood of Participant FX under Fluorescent light. The mood might be predicted, and this information might be used for future purposes.

Overall, four out of five days the feelings of Participant FX observed under Fluorescent light were considered as positive feelings, and one day the participant felt negative emotions under Fluorescent light. Consequently, results shown in Figure 7.14 indicate that the participant felt mainly positive feelings such as pleasure and contentment under Fluorescent light exposures.







PARTICIPANT FX - FLUORESCENT LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3	II	0.22	35.58	7.17
4	II VIII	0.14	35.14	7.56
5	II	0.25	35.31	9.86
6				
7				
8	II	0.34	35.95	7.20
9				
10				
11				
12	IV	0.37	35.61	3.38
13				
14				

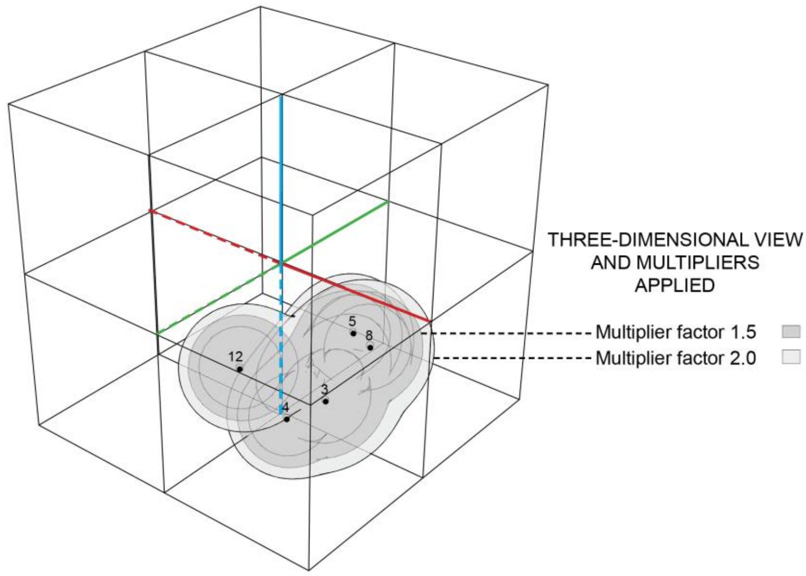


Figure 7. 14. 3D Mood Box of Participant FX under Fluorescent light conditions (displayed in colour grey for a better comprehension). This group of images presents the data from the physiological signals combined of Participant FX under Fluorescent light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Yellow:

Participant FX was exposed to Yellow, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.15, referring to the 3D Mood Box of Participant FX felt under Yellow was the following:

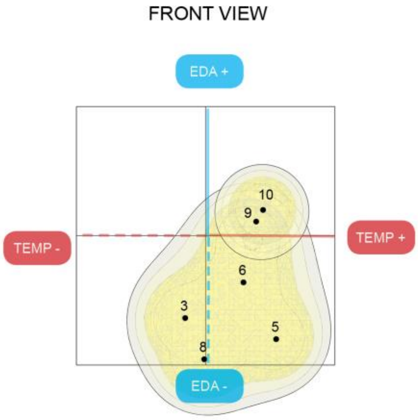
- On day 3, the *metaball* was located in between the QIV and QVI, showing feelings between relaxation and relief and distraction.
- On day 5, the *metaball* was located in QII, showing feelings such as contentment, pleasure and interest.
- Similarly, on day 6, the *metaball* was located in between the QII and QIV, showing feelings between contentment, pleasure and interest and relaxation and relief.
- On day 8, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.
- On day 9, the *metaball* was located in between the QI and QII, showing feelings between excitement and contentment, pleasure and interest.
- On day 10, the *metaball* is located in QIII, showing feelings such as happiness and amusement.

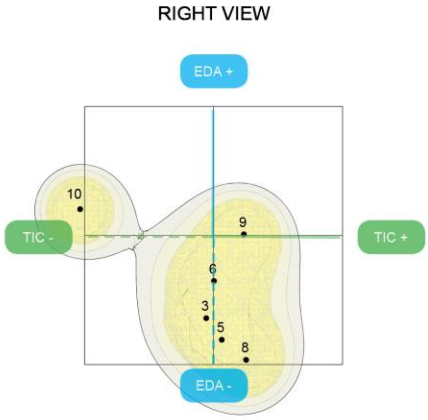
The datasets from days 3, 5, 6, 8 and 9 coalesced with a multiplier factor of 1.5, creating a compacted volume located mainly in Quadrant II and Quadrant VI, indicating that, the majority of the sessions, the predominant feelings that Participant FX might feel under Yellow were contentment, pleasure and interest and distraction.

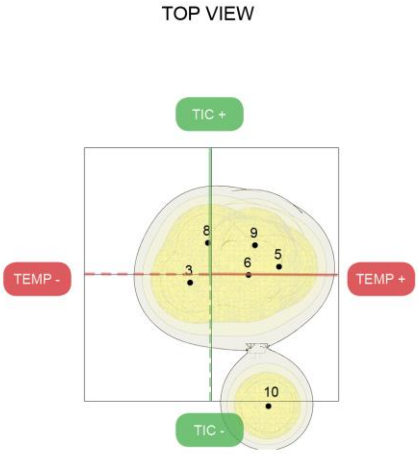
The *metaball* from day 10, however, needed a multiplier factor higher of 2.50 to merge with the volume mentioned.

The volume created with the 1.5 multiplier factor, composed by the majority of the datasets collected and which expanded between Quadrant II and Quadrant VI, indicated that the results observed under Yellow might be consistent. Therefore, these results might shed light on the mood of Participant FX under Yellow. The mood might be predicted, and this information might be used for future purposes.

Overall, four out of six days the feelings of Participant FX observed under Yellow were considered as positive feelings, one day the participant felt neutral emotions, and one day the participant felt negative emotions under Yellow. Consequently, results shown in Figure 7.15 indicate that the participant felt mainly positive feelings such as pleasure and contentment under Yellow LED exposures.







PARTICIPANT FX - YELLOW LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3	IV-VI	0.26	35.00	6.75
4				
5	II	0.22	35.88	7.35
6	II-IV	0.33	35.57	7.00
7				
8	VIII	0.18	35.18	8.28
9	I-II	0.42	35.63	8.16
10	III	0.47	35.76	1.83
11				
12				
13				
14				

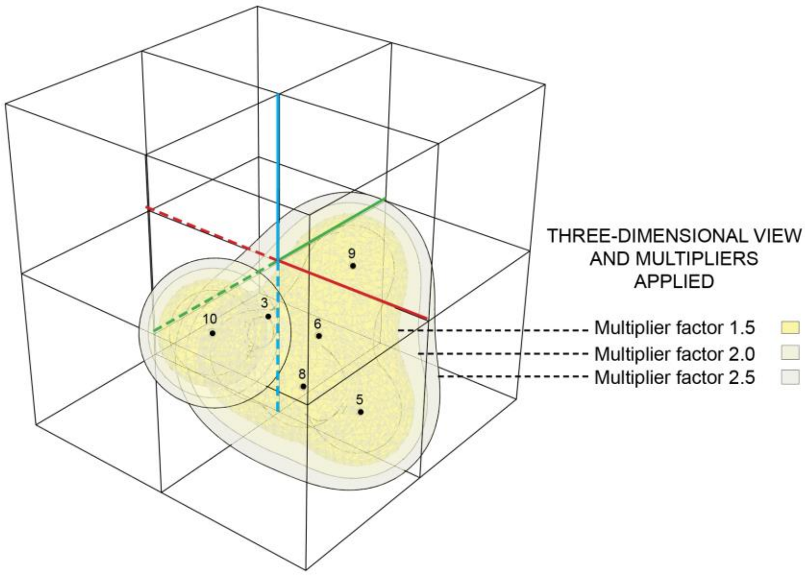


Figure 7. 15. 3D Mood Box of Participant FX under Yellow light conditions (displayed in colour yellow for a better comprehension). This group of images presents the data from the physiological signals combined of Participant FX under Yellow light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Green:

Participant FX was exposed to Green, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.16, referring to the 3D Mood Box of Participant FX felt under Green was the following:

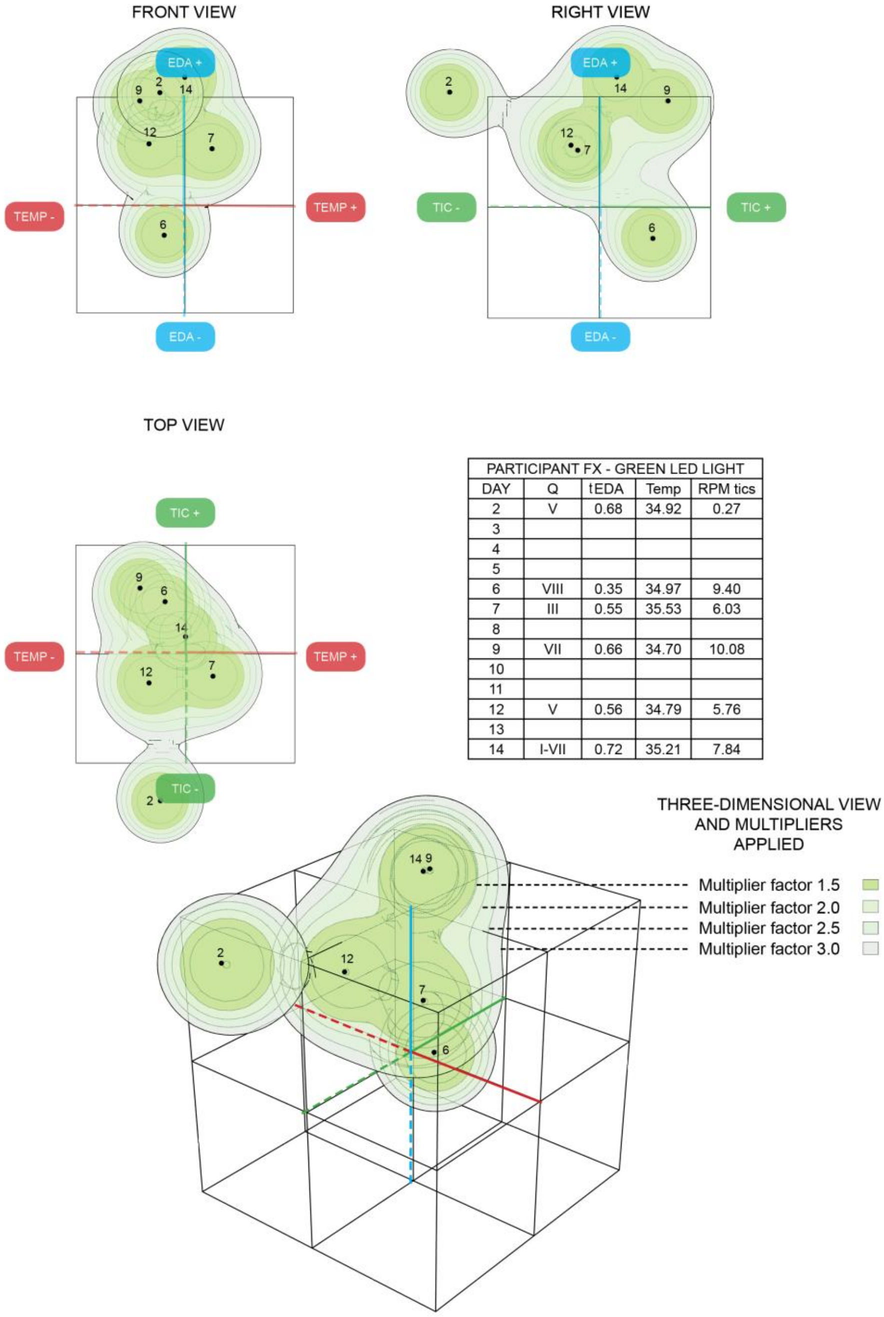
- On days 2 and 12, the *metaballs* were located in the QV, showing feelings such as alertness and mental workload.
- On day 6, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.
- On day 7, the *metaball* was located in QIII, showing feelings such as happiness and amusement.
- On day 9, the *metaball* was located in QVII, showing feelings such as anxiety, stress, anger and overstimulation.
- Similarly, on day 14, the *metaball* was located in between the QI and QVII, showing feelings between excitement and anxiety, stress, anger and overstimulation. Results shown on day 14 under Green might indicate that the feeling could be considered more neutral and standard.

The datasets from days 7, 9, 12, and 12 coalesced with a multiplier factor of 1.5, creating a compacted volume located in the conjunction of Quadrant III, Quadrant V and Quadrant VII, indicating that, the majority of the sessions, the predominant feelings that Participant FX might feel under Green was high arousing feelings such as happiness, alertness, concentration, pleasure and stress and overstimulation. Due to the different nature of the feelings and the equidistant location of the points, it was not easy to elucidate whether the feelings were positive or negative.

The *metaball* from day 2 and 6, however, needed a multiplier factor higher of 3.00 to merge with the volume mentioned.

The volume created with the 1.5 multiplier factor, composed by the majority of the datasets collected and located in the conjunction of Quadrant III, Quadrant V and Quadrant VII, indicated that the results observed under Green might be consistent but the mood might not be predicted. Nevertheless, all the emotions that participant FX experienced under Green were high arousing, and this information might be used for future purposes.

Overall, one out of six days the feelings of Participant FX observed under Green were considered as positive feelings, one day the participant felt neutral emotions, two out of six days the participant was mainly concentrated and two out six days the participant felt negative emotions under Green. Consequently, results shown in Figure 7.16 indicated that the emotions felt by participant FX were between negative and alert or mental workload under Green LED exposures.



PARTICIPANT FX - GREEN LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2	V	0.68	34.92	0.27
3				
4				
5				
6	VIII	0.35	34.97	9.40
7	III	0.55	35.53	6.03
8				
9	VII	0.66	34.70	10.08
10				
11				
12	V	0.56	34.79	5.76
13				
14	I-VII	0.72	35.21	7.84

Figure 7. 16. 3D Mood Box of Participant FX under Green light conditions (displayed in colour green for a better comprehension). This group of images presents the data from the physiological signals combined of Participant FX under Green light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

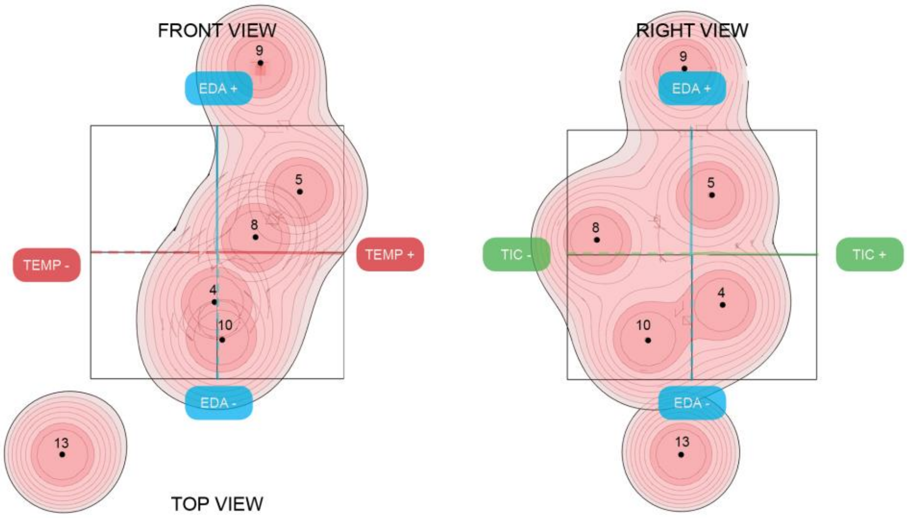
Red:

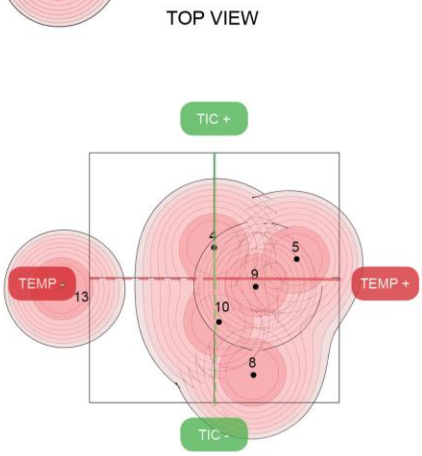
Participant FX was exposed to Red, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.17, referring to the 3D Mood Box of Participant FX felt under Red was the following:

- Two out of six days, on days 8 and 9, the *metaball*s were located in QIII, showing feelings such as happiness and amusement.
- On day 4, the *metaball* was located in between the QII and QVIII, showing feelings between contentment, pleasure and interest and frustration, annoyance, sadness and tiredness.
- On day 5, the *metaball* was located in QI, showing feelings such as excitement.
- On day 10, the *metaball* was located in QIV, showing feelings such as relaxation and relief.
- On day 13, the *metaball* is located in QVI, showing feelings such as distraction.

Only the datasets from days 4 and 10 coalesced with a multiplier factor of 1.5, creating a volume located in the conjunction of Quadrant II, Quadrant IV and Quadrant VIII, indicating that, these two sessions, the predominant feelings that Participant FX might feel under Red were low arousing feelings such as pleasure, relaxation, distraction and tiredness. The rest of the *metaball*s needed a multiplier factor higher of 2.50 to merge. Consequently, no volume was created between the *metaball*s because all the spheres were dispersed in the 3D Mood Box. Therefore, these results indicated that the mood of Participant FX under Red might not be consistent and, thus, the mood could not be predicted.

Overall, four out of six days the feelings of Participant FX observed under Red were considered as positive feelings, one day the participant felt neutral emotions, and one day the participant felt negative emotions under Red. Consequently, results shown in Figure 7.17 indicated that the participant felt mainly positive feelings under Red exposures.





PARTICIPANT FX - RED LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4	II-VIII	0.32	35.20	8.28
5	I	0.54	36.03	7.78
6				
7				
8	III	0.45	35.59	3.19
9	III	0.79	35.63	6.72
10	IV	0.25	35.25	5.24
11				
12				
13	VI	0.02	33.68	6.60
14				

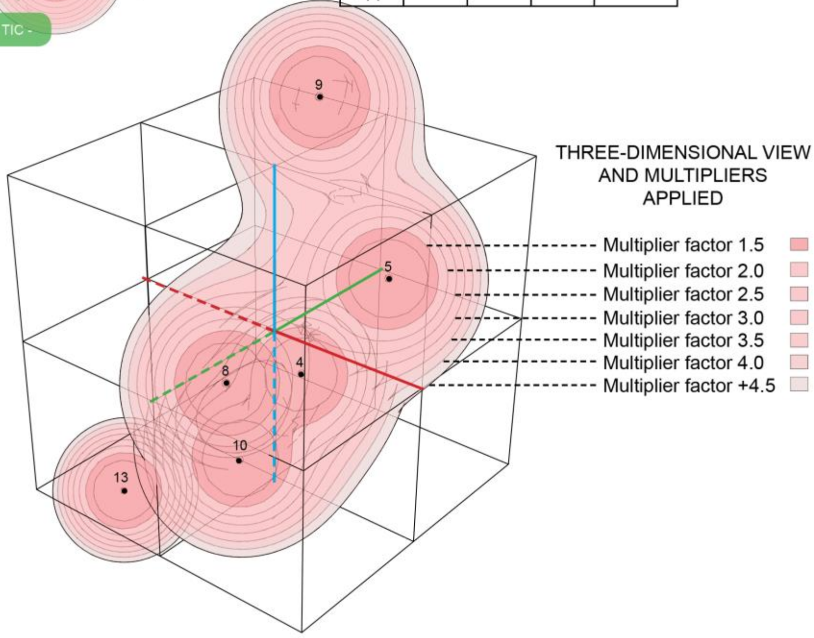


Figure 7. 17. 3D Mood Box of Participant FX under Red light conditions (displayed in colour red for a better comprehension). This group of images presents the data from the physiological signals combined of Participant FX under Red light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Blue:

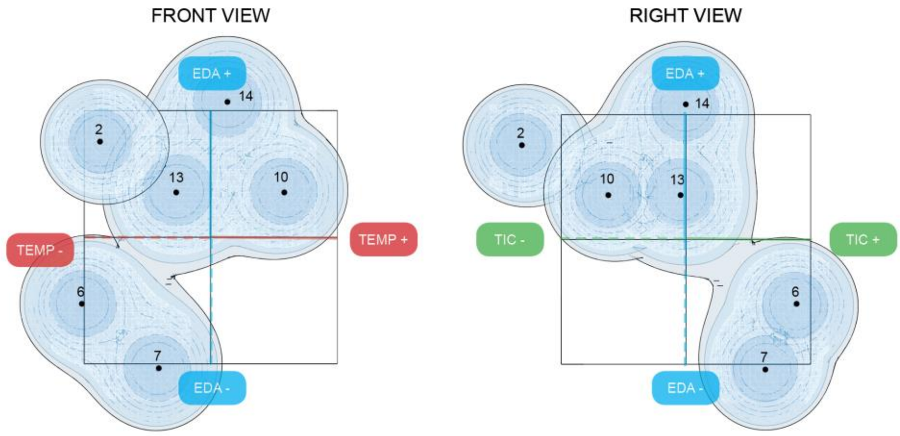
Participant FX was exposed to Blue, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.18, referring to the 3D Mood Box of Participant FX felt under Blue was the following:

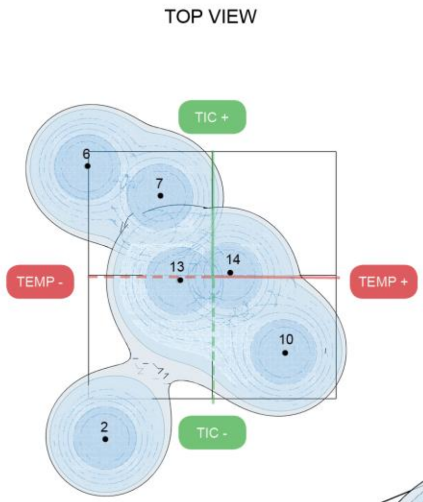
- On day 2, the *metaball* was located in QV, showing feelings such as alertness and mental workload.
- On days 6 and 7, the *metaball* were located in the QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.
- On days 10 and 14, the *metaball* were located in QIII, showing feelings such as happiness and amusement.
- Similarly, on day 13, the *metaball* was located in between the QV and QVII, showing feelings between alertness and mental workload, and anxiety, stress, anger and overstimulation.

None of the observed datasets from Participant FX obtained from Blue exposures merged under a multiplier factor of 1.5 or less. Therefore, no volume was created between the *metaball*s because all the spheres were dispersed in the 3D Mood Box. These results indicated that the mood of Participant FX under Blue might not be consistent and, thus, the mood could not be predicted.

The *metaball*s from days 6 and 7 and the *metaball*s from days 13 and 14 need a multiplier factor of 2.00 to merge into two groups. The first group was located in Quadrant VIII, indicating that the participant might have felt feelings such as frustration, annoyance, sadness and tiredness. The second group was located in the high arousing quadrants, in the origin point. They needed a multiplier factor higher of 4.5 to merge with the rest of the datasets collected from the case study. Therefore, these results indicated, that the mood of Participant FX under Blue might not be consistent and, thus, the mood under Blue could not be predicted.

Overall, two out of six days the feelings of Participant FX observed under Blue were considered as positive feelings, one day the participant was mainly concentrated, and three out of six days the participant felt negative emotions under Blue. Consequently, results shown in Figure 7.18 indicate that the emotions felt by participant FX were mainly negative under Blue exposures.





PARTICIPANT FX - BLUE LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2	V	0.61	34.12	0.43
3				
4				
5				
6	VIII	0.29	33.94	11.44
7	VIII	0.16	34.69	10.23
8				
9				
10	III	0.51	35.94	3.90
11				
12				
13	V-VII	0.51	34.87	6.82
14	III	0.69	35.38	7.04

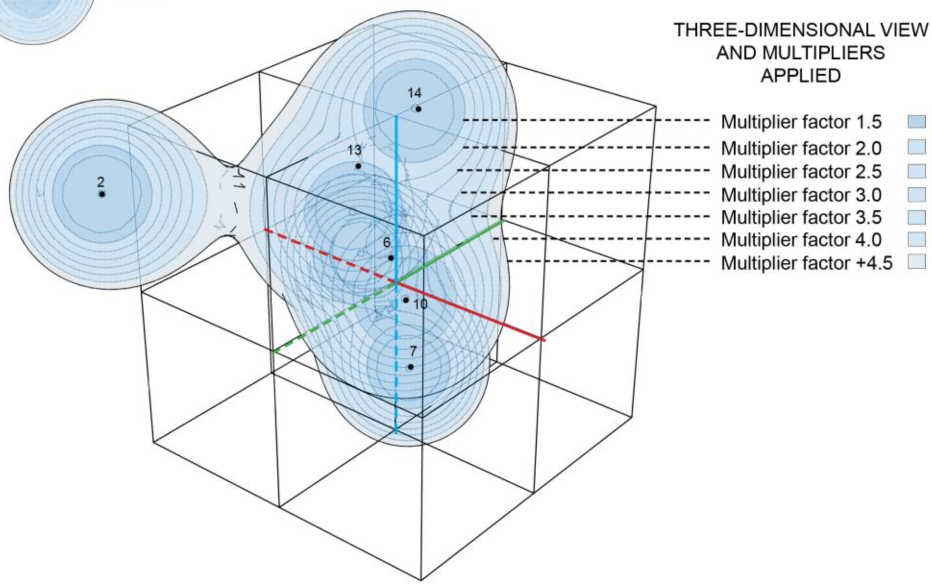


Figure 7. 18. 3D Mood Box of Participant FX under Blue light conditions (displayed in colour blue for a better comprehension). This group of images presents the data from the physiological signals combined of Participant FX under Blue light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Conclusions for Participant FX:

The characteristics of the different volumes created under the different light conditions indicated that the different types of the light do impact differently on the mood of Participant FX.

Comparison between White and Fluorescent. The importance of the source of the light:

Figure 7.19 shows the results obtained from White LED exposures and Fluorescent light exposures for Participant FX. Results indicate that the influence of the White and the Fluorescent light affected the mood of Participant FX differently.

On the one hand, results of White show that the *metaballs* expanded around all the quadrants and did not coalesce with a significant multiplier factor of 1.5. This finding shows no consistency and no prevalence of positive or negative feelings, indicating that the feelings could not be predicted. On the other hand, results under Fluorescent light were consistent and indicated that most of the *metaballs* coalesced with a multiplier factor of 1.5, showing positive feelings of Quadrant II such as pleasure and interest.

These findings indicate that Participant FX showed a significant difference in the mood regarding the source of the light. While feelings under White were so diverse that cannot be predicted, results under Fluorescent light, seemed to induce positive and low arousing mood in the participant. These findings indicate that Fluorescent light could be more suitable than White for Participant FX for calming situations.

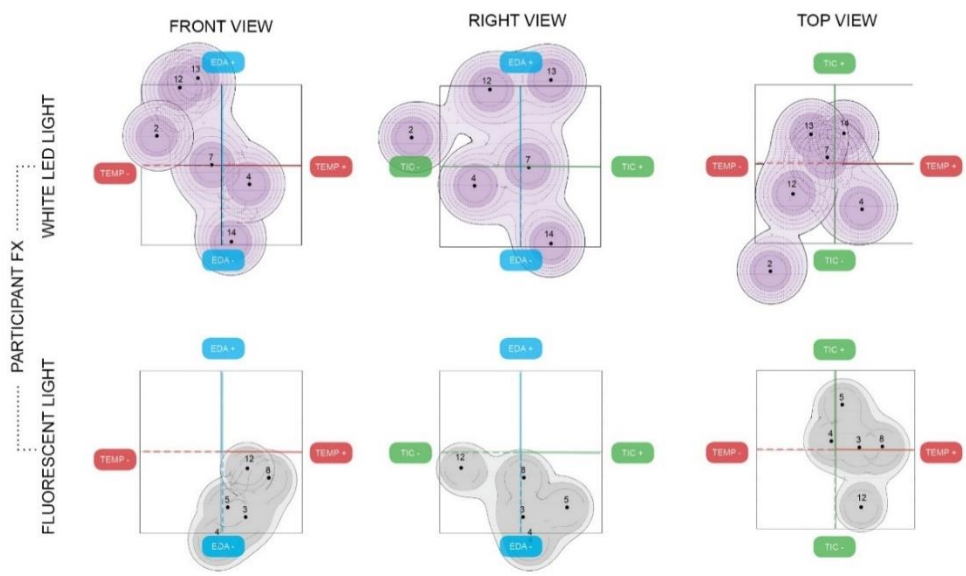


Figure 7. 19. 3D Mood Box of Participant FX under White and Fluorescent Light conditions (displayed in colour purple and grey, respectively). Every metaball is associated with a number, which indicates the day of the dataset was collected.

The influence of the colour of the light on the participant's mood:

Figure 7.20 shows the results obtained under different LED colour lights for Participant FX. On the one hand, results obtained under the coloured LED lighs show that the metaballs from Yellow and Green are consistent and coalesced with a multiplier factor of 1.5 creating different volumes and shapes for every colour. These results indicate that these colours induced different feelings: Yellow seemed to induce low arousing positive feelings such as pleasure and interest. As these results are consistent, this information could be used in the environment to obtain favourable outcomes. However, even though the results under Green were also consistent, the location of the metaballs located in the conjunction of quadrants indicated that the colour Green could induce between negative feelings and alertness or concentration. More samples would be necessary to elucidate whether this light induces one feeling or the other.

On the other hand, results of Red and Blue exposures were not consistent as the majority of the metaballs did not coalesce with a multiplier factor of 1.5. Even though the metaballs did not coalesce, results show that the metaballs obtained from Red were located around the positive quadrants and, consequently, Red could induce positive feelings. Nevertheless, the metaballs obtained from Blue were located around the negative quadrants, indicating that Blue should be avoided.

Considering the results mentioned, in order to improve the well-being and quality of life of Participant FX in the environment Fluorescent light, Yellow and Red could be the more suitable lights to calm him if he were feeling stressed. More information about Green would be necessary to evaluate its influence on Participant FX, and Blue should be avoided as it might provoke frustration, annoyance and tiredness.

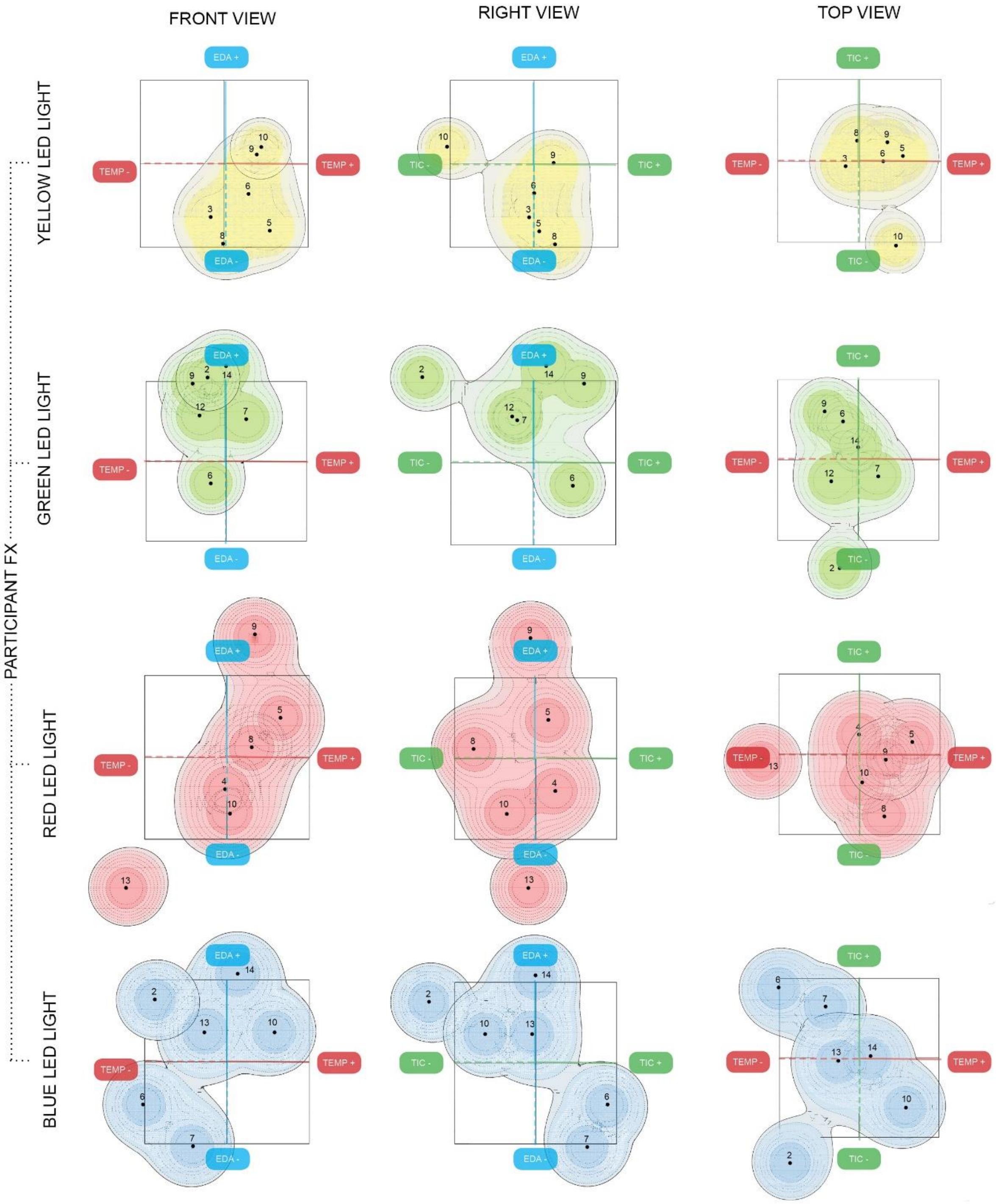


Figure 7. 20. 3D Mood Box of Participant FX under Yellow, Green, Red and Blue conditions (displayed in colour yellow, green, Red and blue, respectively). Every metaball is associated with a number, which indicates the day of the dataset was collected.

7.3.3. Participant H:

Participant H is a young man who has many periods of elevated levels of anxiety. When he suffers from anxiety, he refuses to do any activity and show aggressive behaviour against the property and himself.

The participant could not attend most of the sessions due to health issues provoked by his anxiety levels. Most of the few times the participant could attend the sessions, he also refused to wear the skin conductance sensors. Consequently, reliable results cannot be extracted from this method for Participant H because of the lack of information. Only datasets composed by the three physiological signals could be introduced in this three-dimensional box, so the sample of Participant H was small.

Even though the results cannot be used for future design solutions because most of the times, the results can be merely anecdotic, results did show differences in reactions to the different types of lights.

If it were possible obtain all the data and extract reliable results, the information could be used to create a proper environment which could reduce his anxiety levels and, consequently, his health could improve.

White:

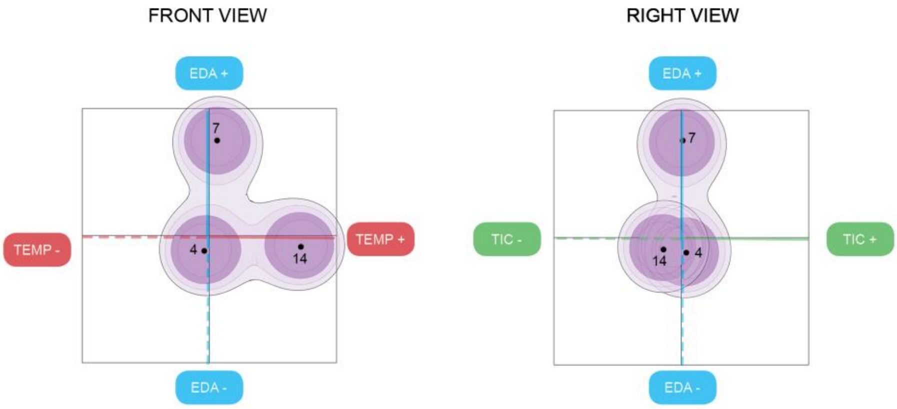
Participant H was exposed to White, with a successful collection of the three complementary types of data, three times. The distribution of the points shown in Figures 7.21, referring to the 3D Mood Box of Participant H felt under White was the following:

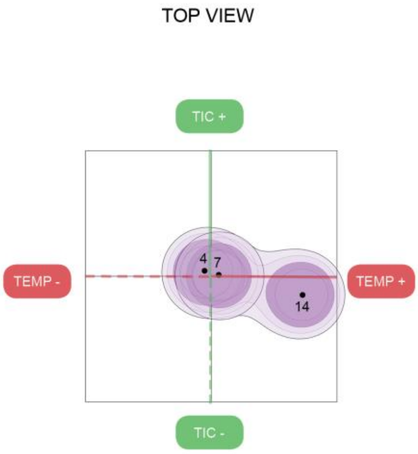
- On day 4, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.
- On day 7, the *metaball* was located in between the QI and QIII, showing feelings between excitement and happiness and amusement.
- On day 14, the *metaball* was located in QIV, showing feelings such as relaxation and relief.

None of the observed datasets from Participant H obtained from White exposures merge under a multiplier factor of 1.5 or less. Therefore, no volume was created between the *metaball*s because all the spheres were dispersed in the 3D Mood Box.

The *metaball*s from days 4 and 14 needed a multiplier factor of 2.00 to merge. These results indicated, that the mood of Participant H under White might not be consistent and, thus, the mood under White could not be predicted.

Overall, two out of three days the feelings of Participant H observed under White were considered as positive feelings, and one day the participant felt negative emotions under the White light. Consequently, results shown in Figure 7.21 indicate that the participant felt mainly positive feelings under White LED exposures.





PARTICIPANT H - WHITE LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4	VIII	0.13	36.45	1.33
5				
6				
7	I III	0.35	36.58	1.19
8				
9				
10				
11				
12				
13				
14	IV	0.14	37.41	0.42

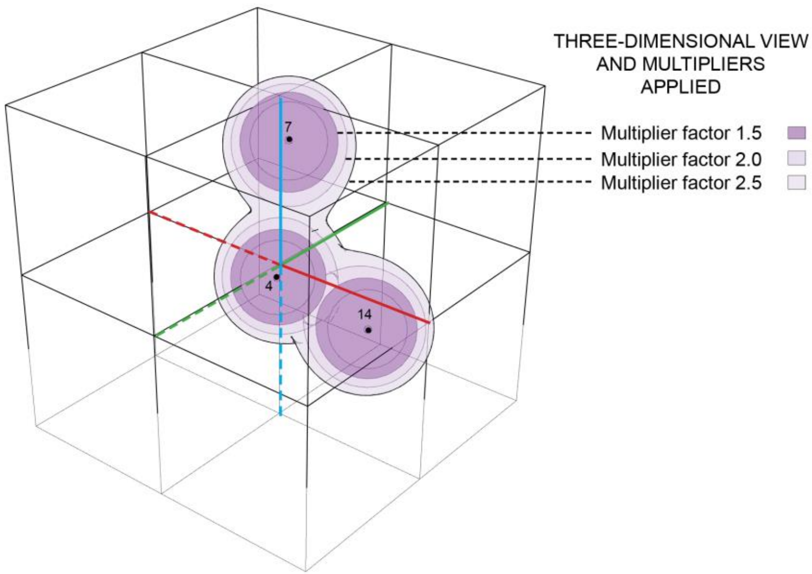


Figure 7. 21. 3D Mood Box of Participant H under White conditions (displayed in colour purple for a better comprehension). This group of images presents the data from the physiological signals combined of Participant H under White LED light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

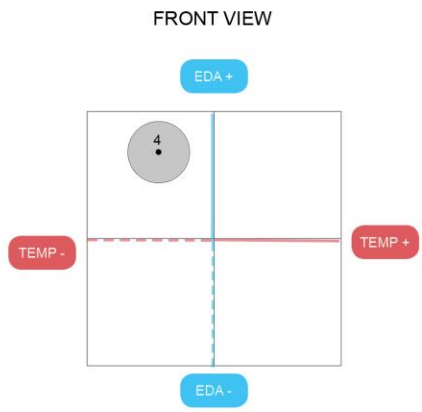
Fluorescent light:

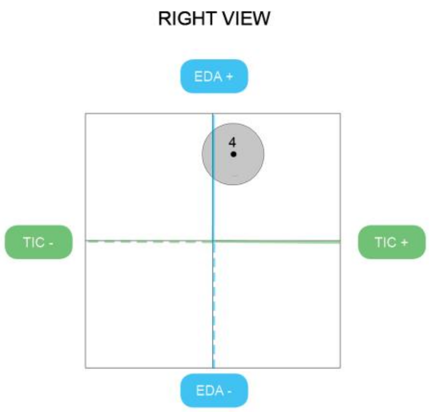
Participant H was exposed to Fluorescent light, with a successful collection of the three complementary types of data, just one time. The location of the point shown in Figures 7.22, referring to the 3D Mood Box of Participant H felt under Fluorescent light was the following:

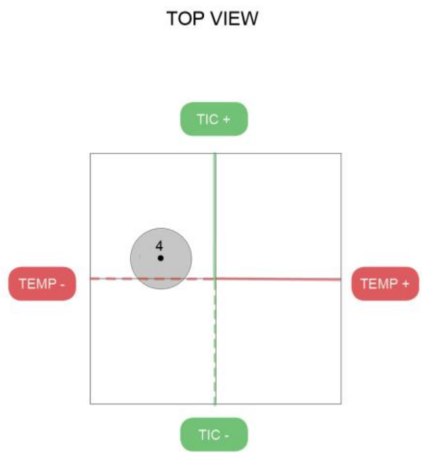
- On day 4, the *metaball* was located in QVII, showing feelings such as anxiety, stress, anger and overstimulation.

The sample was too small so no volumes could be created. The only *metaball* obtained was, as indicated before, in Quadrant VII. However, this result might be anecdotal as there were no other datasets under Fluorescent light with which it could be compared. Therefore, the mood under Fluorescent light could not be predicted.

Unfortunately, there were not enough samples to interpret whether the results obtained were due to the colour of the light or merely anecdotal. However, the results showed that participant H felt negative feelings under the only Fluorescent light exposure.







PARTICIPANT H - FLUORESCENT LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4	VII	0.33	35.96	1.96
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				

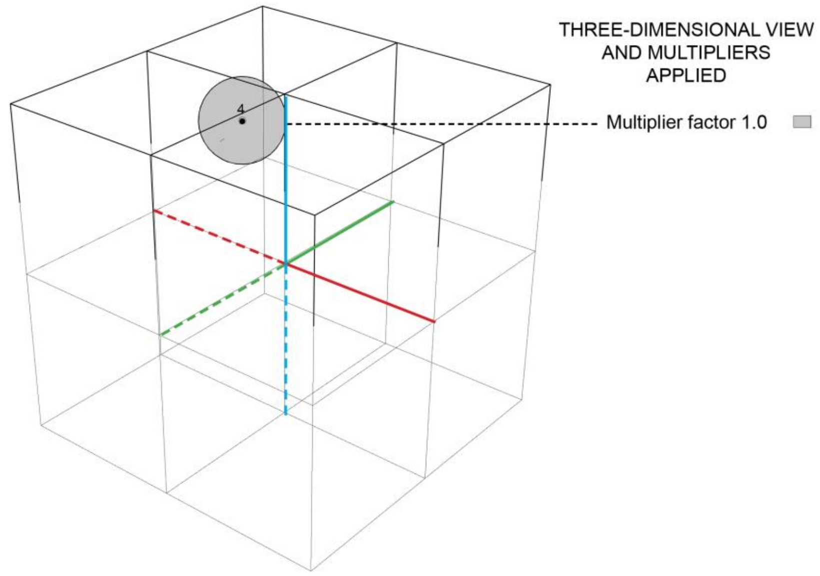


Figure 7. 22. 3D Mood Box of Participant H under Fluorescent light conditions (displayed in colour grey for a better comprehension). This group of images presents the data from the physiological signals combined of Participant H under Fluorescent light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

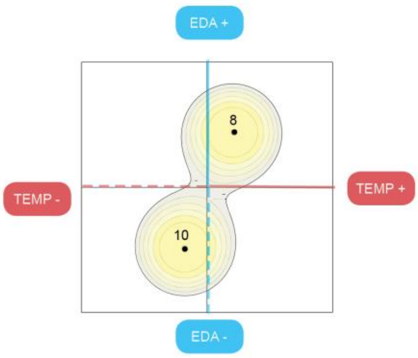
Yellow:

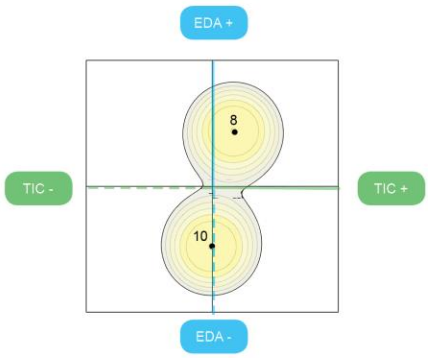
Participant H was exposed to Yellow, with a successful collection of the three complementary types of data, two times. The distribution of the points shown in Figure 7.23, referring to the 3D Mood Box of Participant H felt under Yellow was the following:

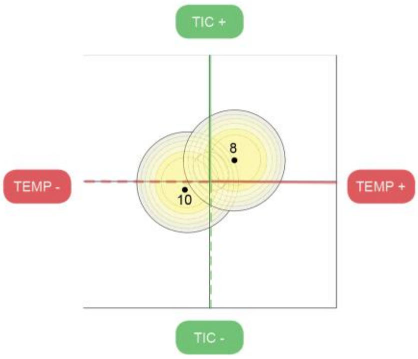
- On day 8, the *metaball* was located in QI, showing feelings such as excitement.
- On day 10, the *metaball* was located in QVI, showing feelings between distraction.

The sample was too small so no volumes were created with a multiplier factor of 1.5. Only two datasets were collected under Yellow whose *metaball*s coalesced with a 3.5 multiplier factor. These results indicated that, apart from the fact that the sample was too small, the few results obtained were not consistent. Therefore, the mood under Yellow could not be predicted.

Overall, one out of two days the feelings of Participant H observed under Yellow were considered as positive feelings, and one out of two days the participant felt negative emotions under Yellow. Consequently, as the sample is too small, results shown in Figure 7.23 were not enough to indicate whether the participant felt mainly positive or negative feelings under Yellow LED exposures.







PARTICIPANT H - YELLOW LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4				
5				
6				
7				
8	I	0.27	36.76	2.01
9				
10	VI	0.04	36.28	1.12
11				
12				
13				
14				

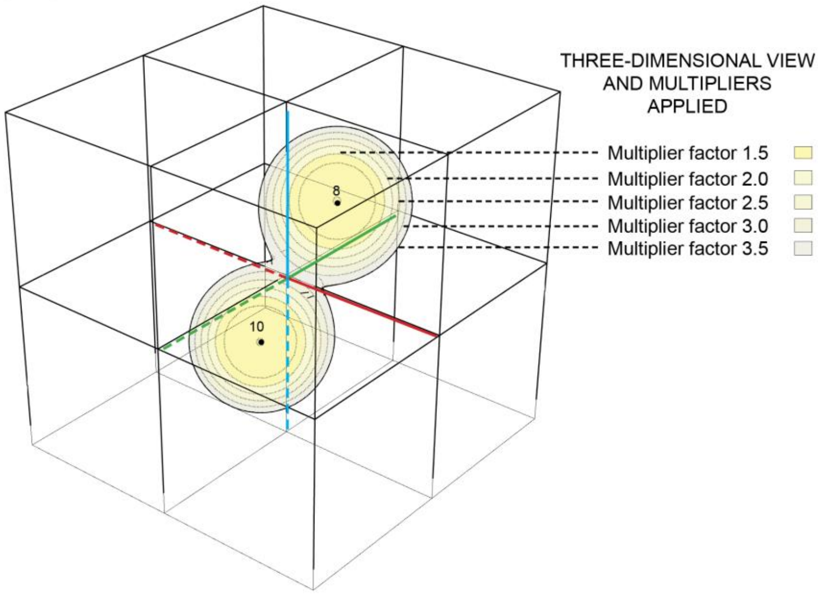


Figure 7. 23. 3D Mood Box of Participant H under Yellow light conditions (displayed in colour yellow for a better comprehension). This group of images presents the data from the physiological signals combined of Participant H under Yellow light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

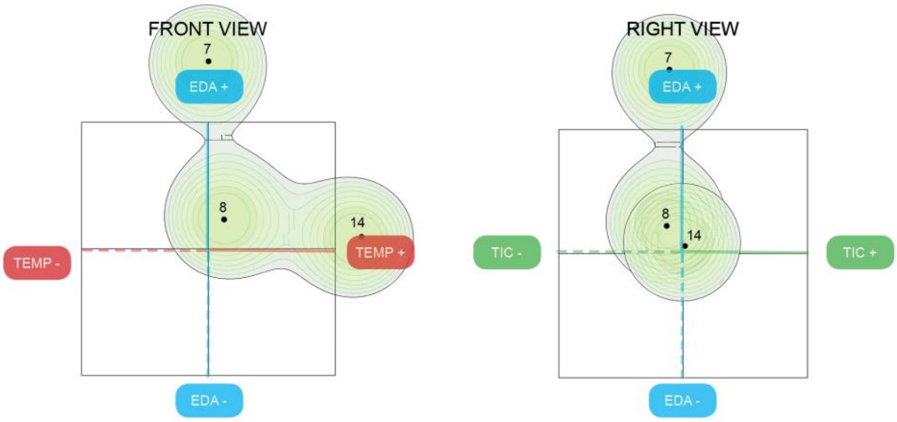
Green:

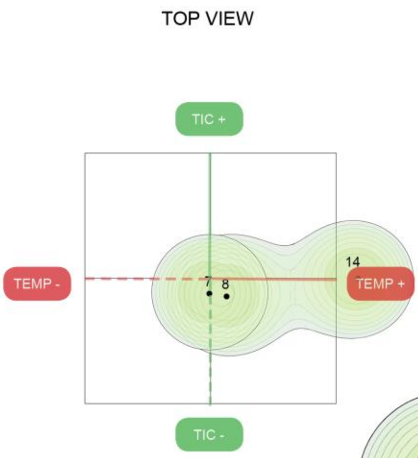
Participant H was exposed to Green, with a successful collection of the three complementary types of data, three times. The distribution of the points is shown in Figure 7.24, referring to the 3D Mood Box of Participant H felt under Green was the following:

- On day 7, the *metaball* was located in QV, showing feelings such as alertness and mental workload.
- On day 8, the *metaball* was located in between the QIII, showing feelings such as happiness and amusement.
- Similarly, on day 14, the *metaball* was located in between the QI and QIII, showing feelings between excitement and happiness and amusement.

The sample was too small so no volumes were created with a multiplier factor of 1.5. Only three datasets were collected under Green whose *metaball*s coalesced with a 4.5 multiplier factor. These results indicated that, apart from the fact that the sample was too small, the few results obtained were not consistent. Therefore, the mood under Green could not be predicted.

Overall, two out of three days the feelings of Participant H observed under Green were considered as positive feelings, and one out of two days the participant felt mainly concentrated under Green. Consequently, results shown in Figure 7.24 indicate that the participant felt mainly positive feelings under Green LED exposures. These results align with the fact that Participant H smiled every time Green LED light was on.





PARTICIPANT H - GREEN LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4				
5				
6				
7	V	0.53	36.49	0.61
8	III	0.22	36.66	0.47
9				
10				
11				
12				
13				
14	I-III	0.18	37.96	1.14

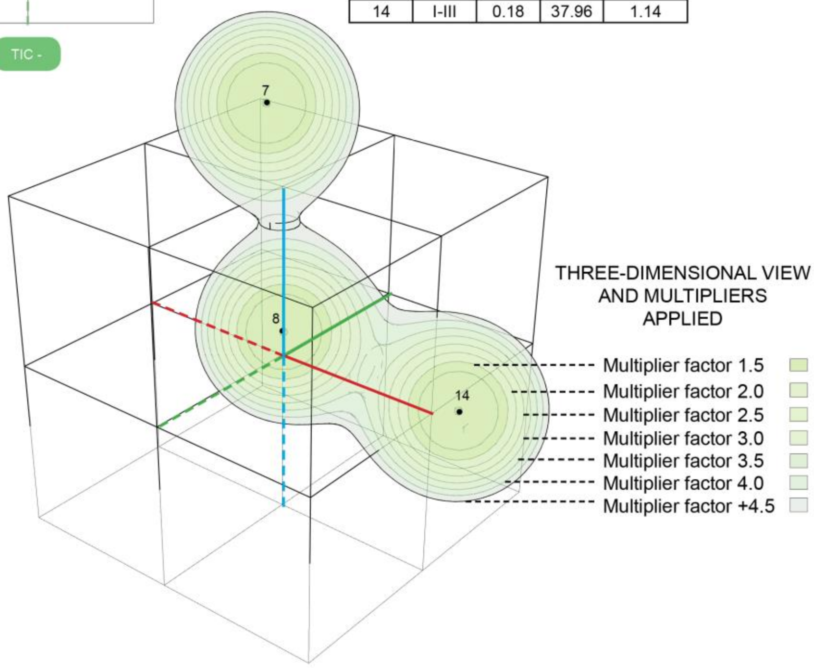


Figure 7. 24. 3D Mood Box of Participant H under Green light conditions (displayed in colour green for a better comprehension). This group of images presents the data from the physiological signals combined of Participant H under Green light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

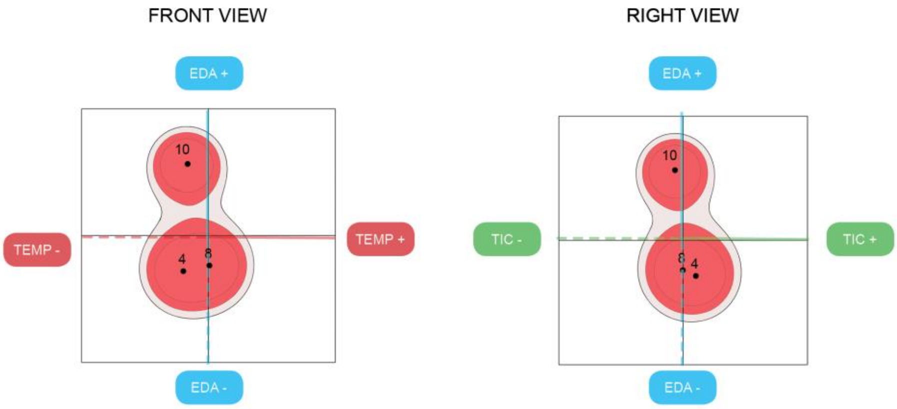
Red:

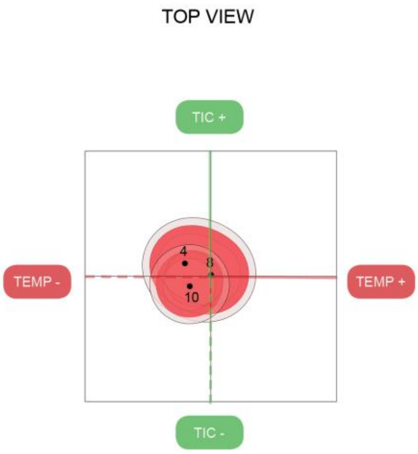
Participant H was exposed to Red, with a successful collection of the three complementary types of data, three times. The distribution of the points shown in Figures 7.25, referring to the 3D Mood Box of Participant H felt under Red was the following:

- On day 4, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance and tiredness.
- On day 8, the *metaball* was located between the QII and IV, showing feelings such as contentment, pleasure and interest and relaxation and relief.
- On day 10, the *metaball* was located in QV, showing feelings such as alertness and mental workload.

The sample was small, but two volumes were created with a multiplier factor of 1.5. Only three datasets were collected under Red, and two of the *metaball*s coalesced with a 1.5 multiplier factor. The third *metaball* coalesced with a 2.0 multiplier factor. These results indicated that, apart from the fact that the sample was too small, the few results obtained were not consistent. Therefore, the mood under Red could not be predicted.

Overall, one out of the three days the feelings of Participant H observed under Red were considered as positive feelings, one out of three days the participant felt mainly concentrated, and one out of three days, the participant felt negative feelings under Red. Consequently, results shown in Figure 7.25 indicate that the participant felt different kind of feelings under Red exposures and the mood could not be predictable with the sample obtained.





PARTICIPANT H - RED LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4	VIII	0.09	36.26	1.68
5				
6				
7				
8	II-IV	0.10	36.52	1.19
9				
10	V	0.30	36.29	0.83
11				
12				
13				
14				

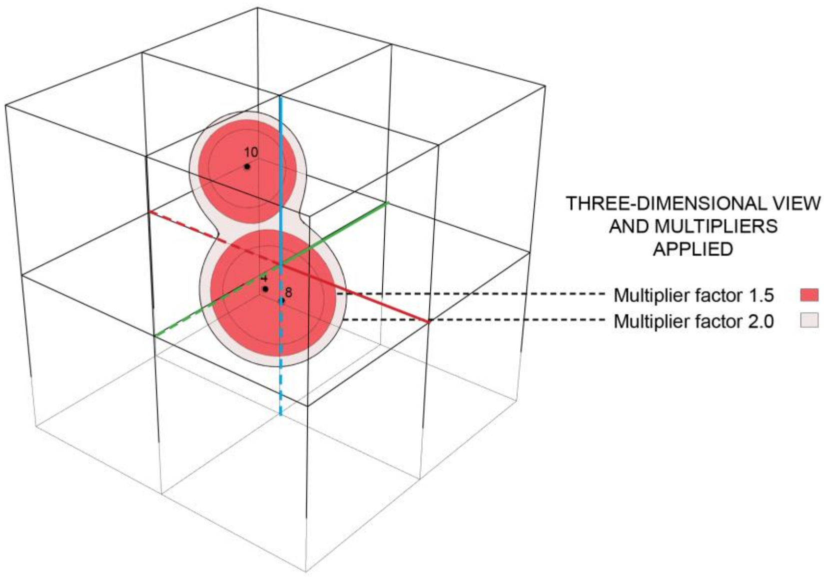


Figure 7. 25. 3D Mood Box of Participant H under Red light conditions (displayed in colour red for a better comprehension). This group of images presents the data from the physiological signals combined of Participant H under Red light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

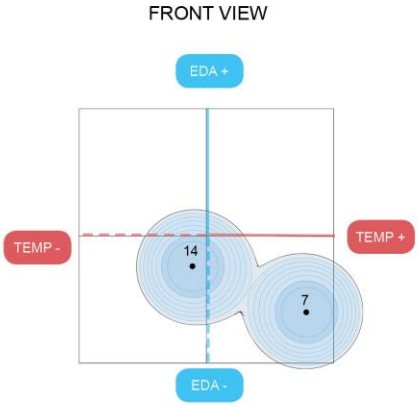
Blue:

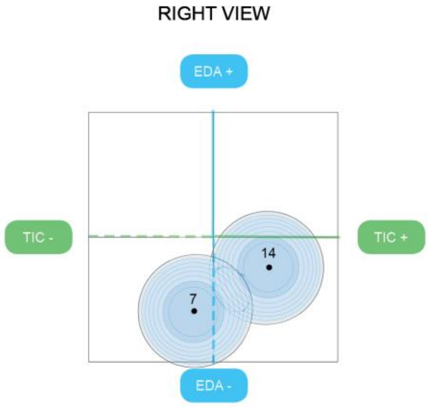
Participant H was exposed to Blue, with a successful collection of the three complementary types of data, two times. The distribution of the points shown in Figures 7.26, referring to the 3D Mood Box of Participant H felt under Blue was the following:

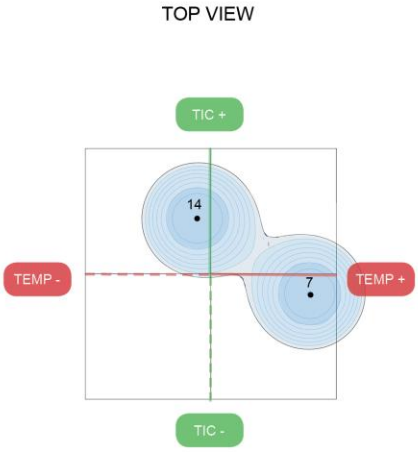
- On day 7, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.
- On day 14, the *metaball* was located in QIV, showing feelings such as relaxation and relief.

The sample was too small so no volumes were created with a multiplier factor of 1.5. Only two datasets were collected under Blue and these *metaball*s coalesced with a 4.5 multiplier factor. These results indicated that, apart from the fact that the sample was too small, the few results obtained were not consistent. Therefore, the mood under Blue could not be predicted.

Overall, one out of two days the feelings of Participant H observed under Blue were considered as positive feelings, and one out of two days, the participant felt negative emotions under Blue. Consequently, as the sample was too small, results shown in Figure 7.26 were not enough to indicate whether the participant felt mainly positive or negative feelings under Blue exposures.







PARTICIPANT H - BLUE LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4				
5				
6				
7	VIII	0.10	36.37	3.38
8				
9				
10				
11				
12				
13				
14	IV	0.01	37.49	0.37

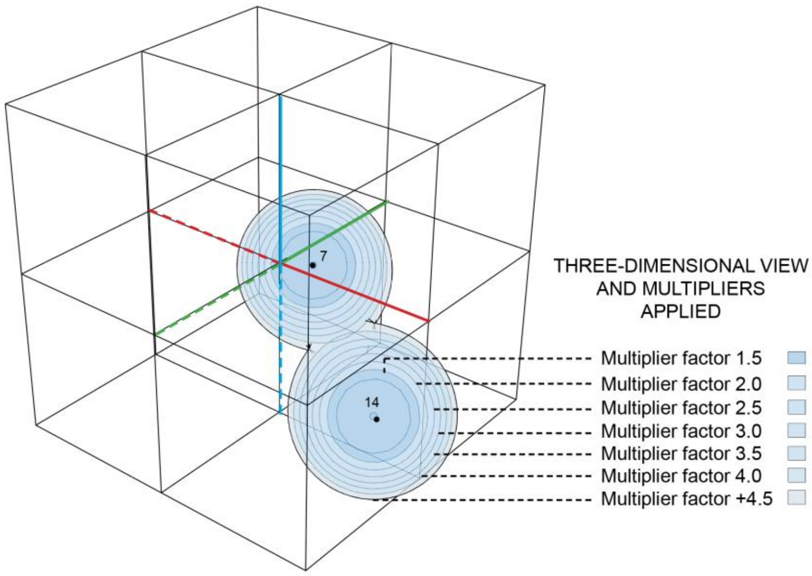


Figure 7. 26. 3D Mood Box of Participant H under Blue light conditions (displayed in colour blue for a better comprehension). This group of images presents the data from the physiological signals combined of Participant H under Blue light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Conclusions for Participant H:

As previously mentioned, the sample is too small to make conclusions about the influence of the different colours and source of the light for Participant H.

Comparison between White and Fluorescent. The importance of the source of the light:

Figure 7.27 shows the results obtained from White LED exposures and Fluorescent light exposures for Participant H. Results indicate that the influence of the White, and the Fluorescent light could affect the mood of Participant H differently.

Results of White show that the *metaballs* are dispersed and expand around the quadrants and did not coalesce with a significant multiplier factor of 1.5. Even though there was no consistency showing particular feelings under White, there was observed a prevalence of positive feelings under White light.

However, the only sample obtained under Fluorescent light indicates that the participant felt stressed and overstimulated under Fluorescent light.

Taking into account that the sample is too small to compare, these findings would indicate that Participant H showed a difference in the mood regarding the source of the light and that Fluorescent light, seem to induce negative mood in the participant and this light should then be avoided.

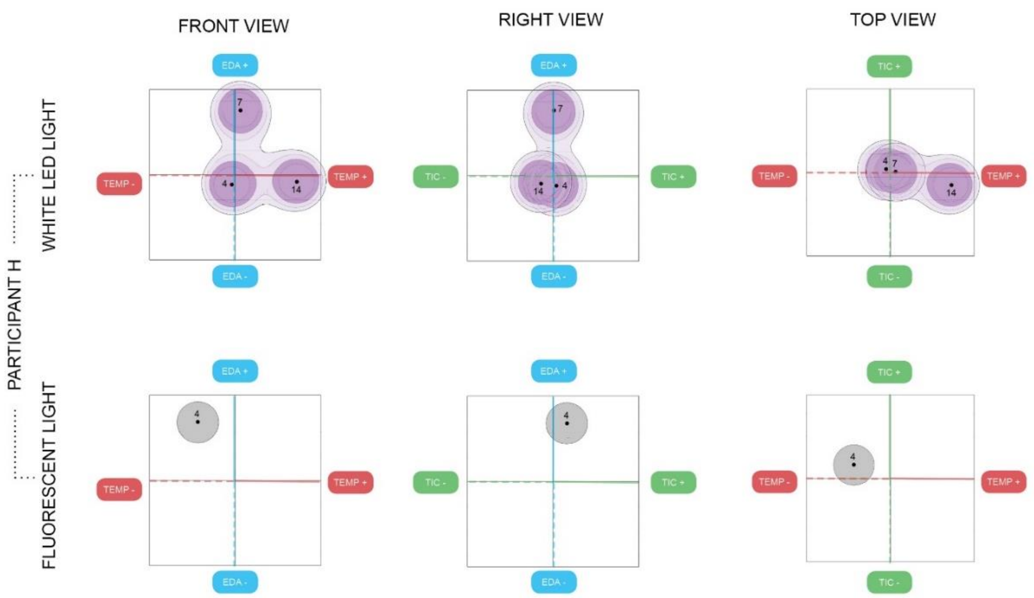


Figure 7. 27. 3D Mood Box of Participant H under White and Fluorescent Light conditions (displayed in colour purple and grey, respectively). Every metaball is associated with a number, which indicates the day of the dataset was collected.

The influence of the colour of the light on the participant's mood:

Figure 7.28 shows the results obtained under different LED colour lights for Participant H. Results obtained under the different coloured lights might be merely anecdotic due to the small sample.

Based on the few exposures obtained for Participant H, none of the metaballs of any coloured light coalesced with a multiplier factor of 1.5, so no volumes and shapes were created for any colour. These results indicate that this information could not be used in the environment to obtain different outcomes.

Only two datasets were obtained, from Yellow and Blue lights, and results show that these colours of the light seemed to induce both positive and negative feelings to Participant H.

Three datasets were obtained from Green and Red lights. Results obtained under Green show that the majority of the times, this light seemed to induce positive feelings to Participant H. This light also seemed to induce alertness or mental workload to the participant. Results obtained under Red show that one of the times, this light seemed to induce positive feelings to Participant H, another time this light seemed to induce alertness, concentration, and the third time, the light seemed to induce negative feelings to the participant, so Red seemed to be unpredictable.

Considering the results mentioned, in order to improve the well-being and quality of life of Participant H in the environment, the few lights which seemed to induce a majority of positive feelings were White, and Green. However, a more significant sample would be necessary to understand which lights would be more beneficial for the mood of participant H.

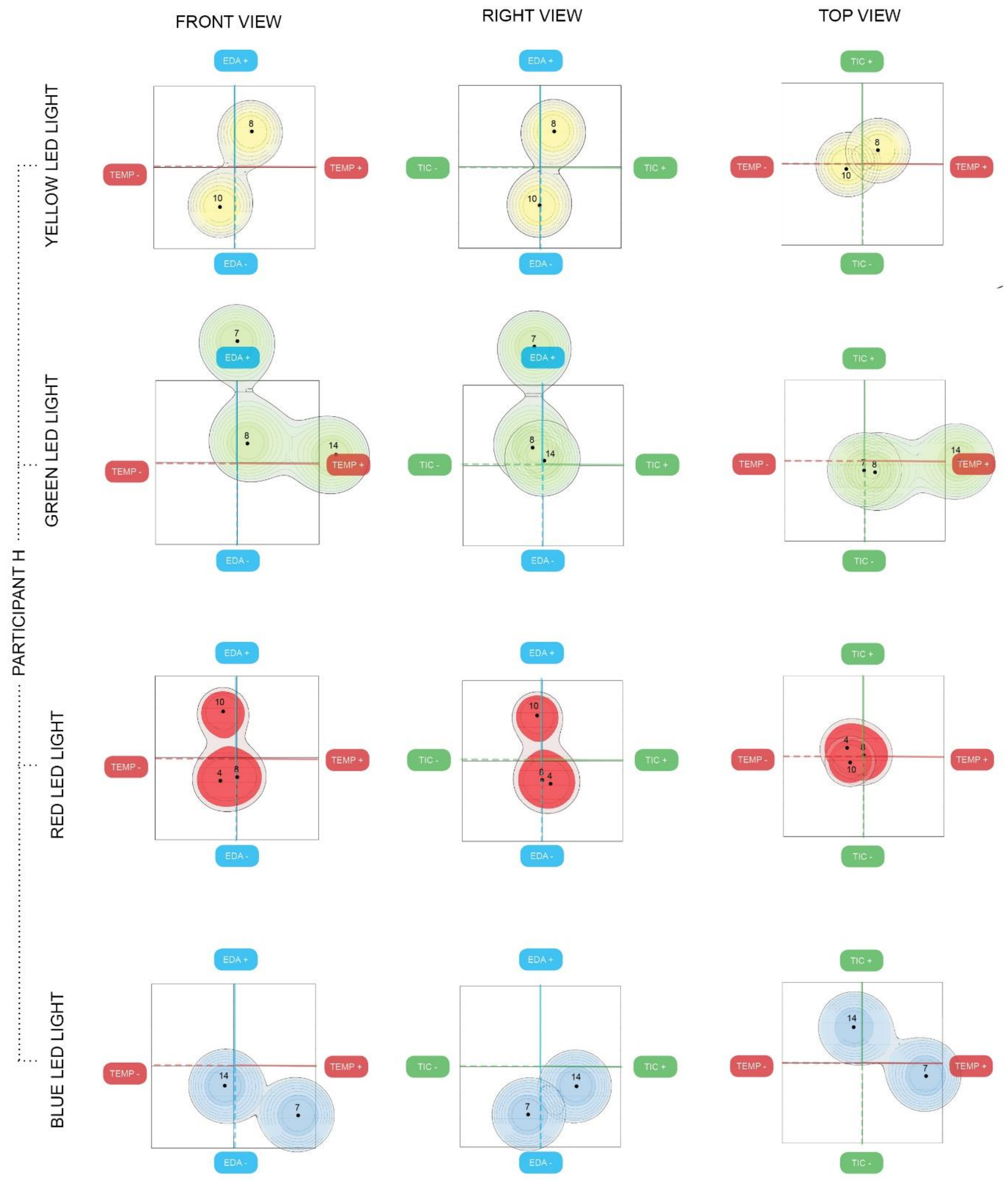


Figure 7. 28.. 3D Mood Box of Participant H under Yellow, Green, Red and Blue conditions (displayed in colour yellow, green, red and blue, respectively). Every metaball is associated with a number, which indicates the day of the dataset was collected.

7.3.4. Participant J:

Participant J is a very controlling and collaborative young man who seemed to enjoy the sessions most of the times. He felt incredibly curious about all the equipment used for the study and, sometimes, he got distracted by this technology.

He seemed to enjoy the Blue light a lot because he asked to change the colour of the light to Blue many times. He also showed aversion to the Red, asking to change the colour of the light most of the times this light was on and showing aggressive behaviour in a few of these occasions.

His cognitive levels are higher than the rest of the participants, and sometimes he asked to change the colour of the light. As mentioned in Chapter Five, as the participant wanted to change the colour of the light sometimes, the sessions suffered few alterations in the sequences of light, and there are few things to bear in mind when analysing the results from each light exposure.

First, as Participant J sometimes asked for a change in the colour of the light, he experienced light exposures of less than 30 seconds which might not show alterations in the physiological signals such as electrodermal activity; therefore, these values might not be comparable to the ones obtained during longer exposures. These exposures are symbolised in the table with the symbol (*).

Secondly, Participant J also asked for darker versions of the colour blue. The new tone was obtained by changing only the hue of the light, maintaining the saturation and the intensity so that they were the same as the rest of the light exposures. These exposures are symbolised in the table with the symbol (+). Different values of the hue can influence the individual differently.

Therefore, even though the exposures with new different hues or different duration were considered as “Blue” for easier comprehension, the changes were noted so any alterations in the results could be considered and discussed in the future.

As both the duration and the change of hue can impact on the mood of the participant differently, two different analyses were performed:

- Analysis A: mood analysis taking into consideration all the light exposures that the participant experienced.

- Analysis B: mood analysis only considering the light exposures longer than 30 seconds and the ones which preserved the light properties established on Chapter Three.

Analysis A:

White:

Participant J was exposed to White, with a successful collection of the three complementary types of data, seven times. The distribution of the points shown in Figures 7.29, referring to the 3D Mood Box of Participant J felt under White was the following:

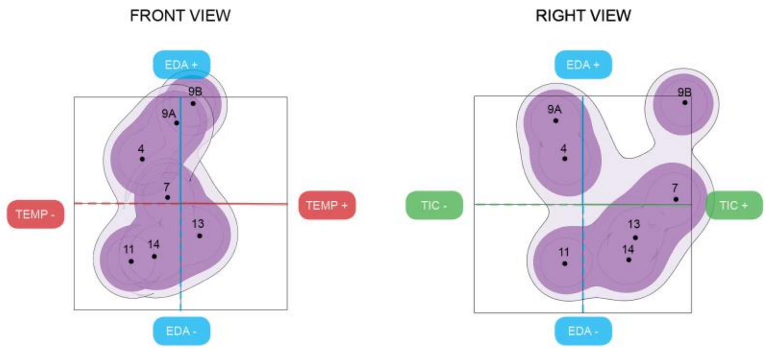
- On day 3, the *metaball* was located in QV, showing feelings such as alertness and mental workload.
- On day 7, the *metaball* was located in QVII, showing feelings between anxiety, stress, anger and overstimulation.
- On day 9, Participant J was exposed to White two times. The first time the *metaball* was located in QV, showing feelings such as alertness and mental workload. The second time the *metaball* was located in QI, showing feelings such as excitement.
- On day 11, the *metaball* was located in QVI, showing feelings such as distraction.
- On day 13, the *metaball* was located in QII, showing feelings such as pleasure and interest.
- On day 14, the *metaball* is located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.

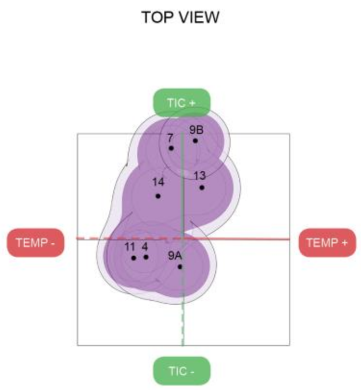
The datasets from days 7, 11, 13 and 14 coalesced with a multiplier factor of 1.5, creating a volume located between Quadrant II, Quadrant VI and Quadrant VIII, indicating that, in more than half of the sessions, the predominant feelings that Participant J might feel under White were distraction, interest, annoyance and tiredness. The *metaball*s from days 4 and 9 also coalesced with a multiplier factor of 1.5. The volume created was located in Quadrant V, indicating that Participant J might be concentrated these days.

All the *metaball*s collected, including also the *metaball* from a second exposure on day 9, would only need a multiplier factor of 2.00 to merge, creating a significant volume located between Quadrants V, VI, VII and VIII. These results indicate that Participant J might not have experienced positive feelings under White light.

This finding indicates that the results observed under White might be consistent. Therefore, the mood might be predicted, and this information might be used for future purposes.

Overall, two out of seven days the feelings of Participant J observed under White were considered as positive feelings, three out of seven days the participant felt negative emotions, and two out of seven days the participant felt mainly concentrated under White light. Consequently, results shown in Figure 7.29 indicate that the participant felt mainly negative feelings under the White LED exposures.





PARTICIPANT J - WHITE LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4	V	0.40	35.50	1.68
5				
6				
7	VII	0.31	35.80	6.80
8				
9 A	V	0.49	35.90	1.25
9 B	I	0.53	36.09	7.20
10		-	-	
11	VI	0.16	35.36	1.65
12		-	-	-
13	II	0.22	36.16	4.96
14	VIII	0.17	35.64	4.64

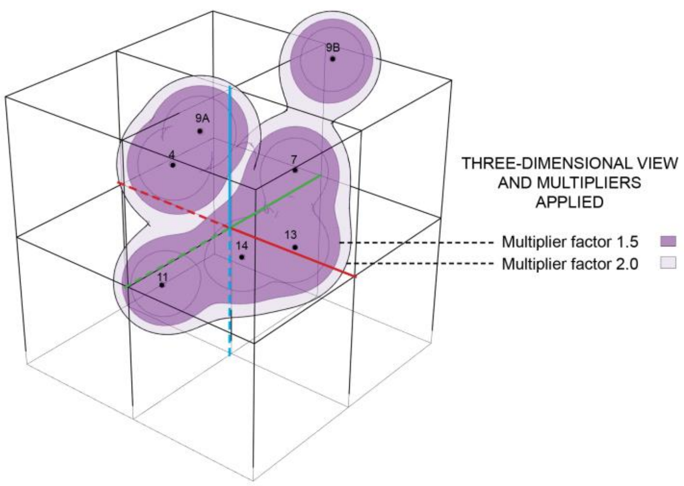


Figure 7. 29. 3D Mood Box of Participant J under White conditions (displayed in colour purple for a better comprehension) for Analysis A and B. This group of images presents the data from the physiological signals combined of Participant H under White LED light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Fluorescent light:

Participant J was exposed to Fluorescent light, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.30, referring to the 3D Mood Box of Participant J felt under Fluorescent light was the following:

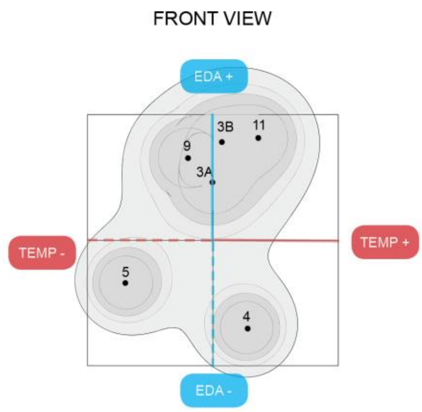
- On day 3, Participant J was exposed to Fluorescent light twice. The first time the *metaball* was located between QIII and QV, showing feelings between happiness and amusement and alertness and mental workload. Similarly, the second time, the *metaball* was located in QIII, showing feelings such as happiness and amusement.
- On day 4, the *metaball* was located in QIV, showing feelings such as relaxation and relief.
- On day 5, the *metaball* was located in QVI, showing feelings such as distraction.
- On day 9, the *metaball* was located in QVII, showing feelings such as anxiety, stress, anger and overstimulation.
- On day 11, the *metaball* was located in QIII, showing feelings such as happiness and amusement.

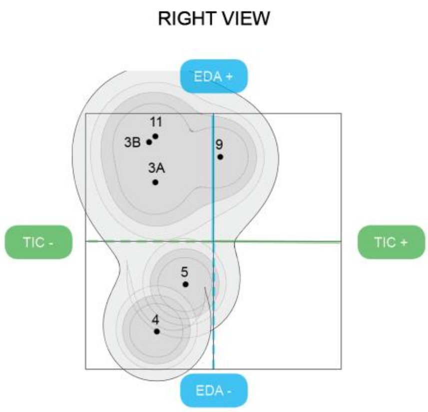
The datasets from days 3, 9 and 11 coalesced with a multiplier factor of 1.5, creating a volume located between Quadrant III and V, indicating that the predominant feeling that Participant J might feel under Fluorescent light was happiness, amusement or alertness, concentration.

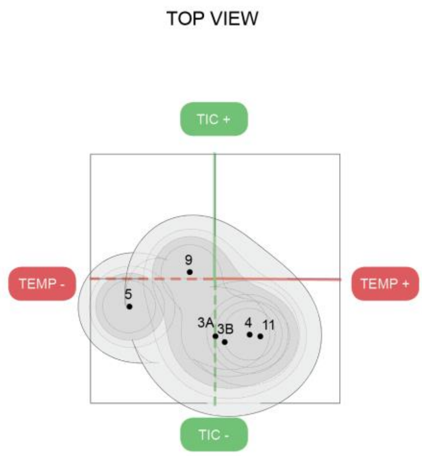
The *metaball*s from days 4 and 5 needed a multiplier factor higher of 2.50 to merge with the rest of *metaball*s.

The volume created with the 1.5 multiplier factor, composed by the majority of the datasets collected and which expanded between Quadrant III and V, indicated that the results observed under Fluorescent light might be consistent. Therefore, even though the sample was small, these results might shed light on the mood of Participant J under Fluorescent light. The mood might be predicted, and this information might be used for future purposes.

Overall, three out of six days the feelings of Participant J observed under Fluorescent light were considered as positive feelings, two out of six days the participant felt negative emotions, and one out of six days the participant felt mainly concentrated under Fluorescent light. Consequently, results shown in Figure 7.30 indicated that the participant felt more positive feelings than negative feelings under Fluorescent light exposures although the prevalence is not too strong.







PARTICIPANT J - FLUORESCENT LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3 A	III-V	0.41	35.95	0.22
3 B	III	0.49	36.04	0.00
4	IV	0.12	36.29	0.30
5	VI	0.21	35.08	1.42
6				
7				
8				
9	VII	0.46	35.69	2.80
10				
11	III	0.50	36.40	0.24
12				
13				
14				

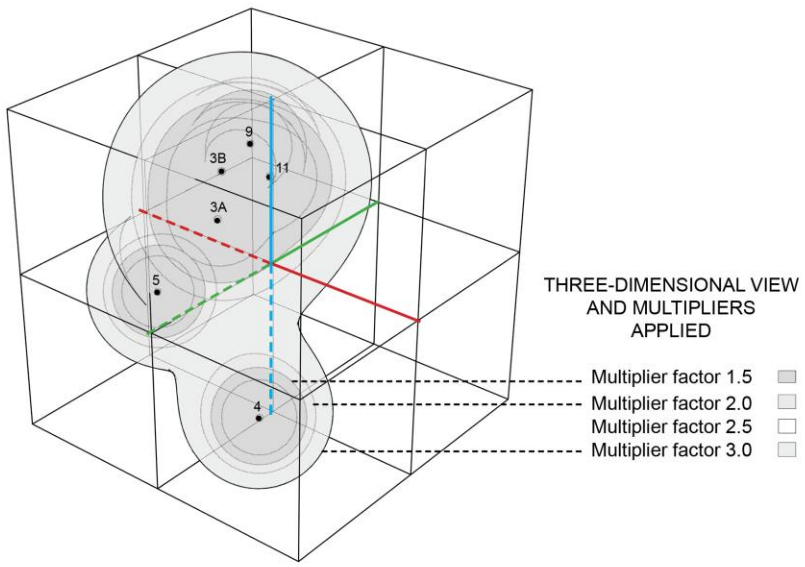


Figure 7. 30. 3D Mood Box of Participant J under Fluorescent light conditions (displayed in colour grey for a better comprehension) for Analysis A and B. This group of images presents the data from the physiological signals combined of Participant J under Fluorescent light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Yellow:

Participant J was exposed to Yellow, with a successful collection of the three complementary types of data, seven times. The distribution of the points shown in Figures 7.31, referring to the 3D Mood Box of Participant J felt under Yellow was the following:

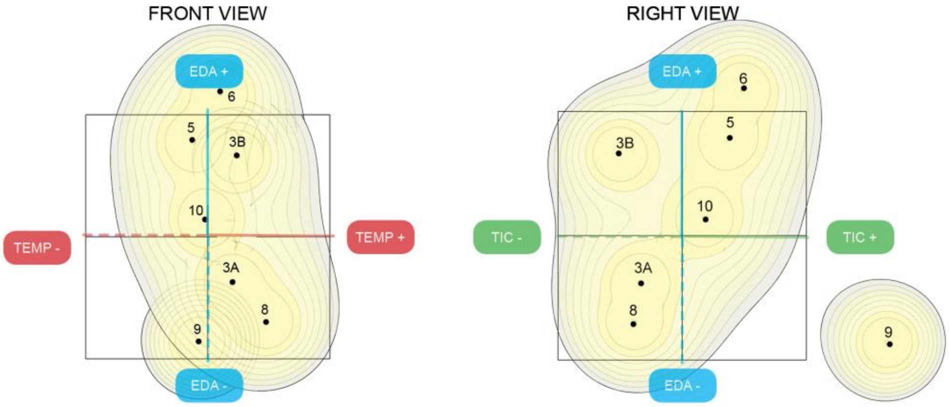
- On day 3, Participant J was exposed to Yellow two times, the first time, similarly to results on day 8, the *metaball* was located in QIV, showing feelings such as relaxation and relief. The second time, the *metaball* was located in QIII, showing feelings such as happiness and amusement.
- Two out of seven times, on days 5 and 10, the *metaball* was located in QVII, showing feelings such as anxiety, stress, anger and overstimulation.
- On day 6, the *metaball* was located in QI, showing feelings such as excitement.
- On day 9, the *metaball* was located in QIV, showing feelings such as frustration, annoyance, sadness and tiredness.

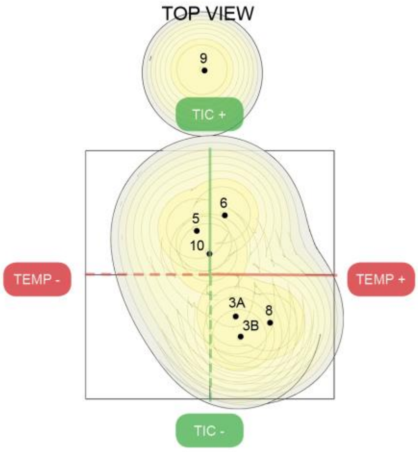
The datasets from days 3, 8, 5, 10 and 6 coalesced with a multiplier factor of 1.5, creating a worm shape volume located between Quadrant IV and VII, indicating that the predominant feelings that Participant J might feel under Yellow moved from relaxation and relief to *anxiety, stress, anger and overstimulation*.

One of the two *metaball*s from day 3 merged with a multiplier factor of 2.00. However, the *metaball* from day 9 only merged with a multiplier factor higher than 4.50.

The volume created with the 1.5 multiplier factor, composed by the majority of the datasets collected and which expanded between Quadrant IV and VII, indicates that the results observed under Yellow might be consistent. Therefore, these results might shed light on the mood of Participant J under Yellow light. The mood might be predicted, and this information might be used for future purposes.

Overall, four out of seven days the feelings of Participant J observed under Yellow were considered as positive feelings, and three out of seven days the participant felt negative emotions under Yellow. Consequently, results shown in Figure 7.31 indicated that the participant felt more positive feelings than negative feelings under Yellow exposures. However, as the meatball created when increasing the spheres by 1.5 was located between QIV and QVII, close to the origin point, it can be said that Participant J felt neutral or standard feelings with a slight tendency to positive feelings.





PARTICIPANT J - YELLOW LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3 A	IV	0.20	36.20	0.84
3 B	III	0.46	36.25	0.00
4				
5	VII	0.49	35.80	4.40
6	I	0.59	36.08	4.98
7				
8	IV	0.12	36.55	0.60
9	VIII	0.08	35.87	10.80
10	VII	0.33	35.93	3.46
11				
12				
13				
14				

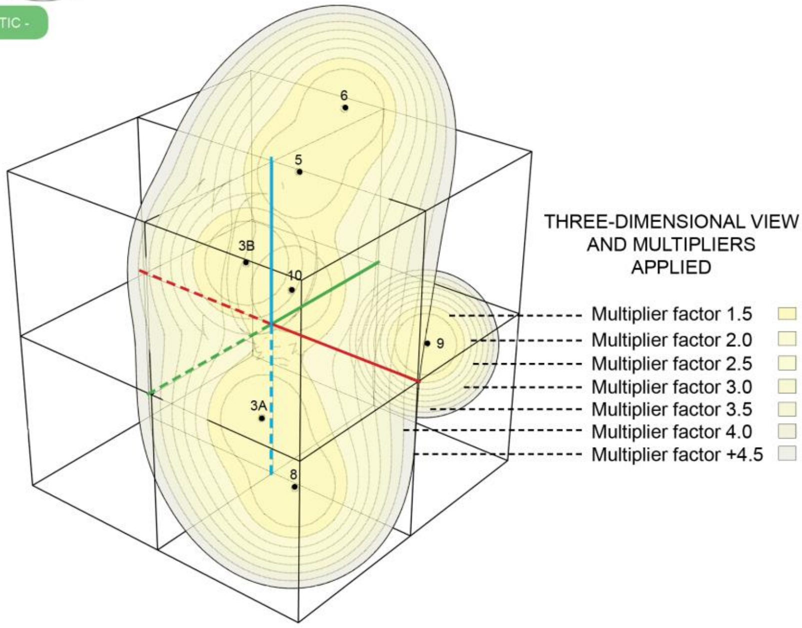


Figure 7. 31. 3D Mood Box of Participant J under Yellow light conditions (displayed in colour yellow for a better comprehension) for Analysis A and B. This group of images presents the data from the physiological signals combined of Participant J under Yellow light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Green:

Participant J was exposed to Green, with a successful collection of the three complementary types of data, seven times. The distribution of the points shown in Figures 7.32, referring to the 3D Mood Box of Participant J felt under Green was the following:

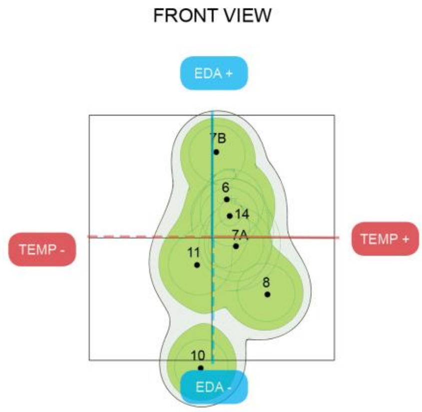
- On day 6, the *metaball* was located in QI, showing feelings such as excitement.
- On day 7, Participant J was exposed to Green two times, both times, similarly to results on day 6, the *metaball* was located in QI, showing feelings such as excitement. Even though the first time the light was set in day 7 the exposure lasted less than 30 seconds, the results are consistent with the other exposure set in the same day. However, this time, similarly to results on day 8, the *metaball* was located very close to QII.
- Two out of seven times, on days 10 and 11, the *metaball* was located in QVIII, showing feelings such as anxiety, stress, anger and overstimulation.
- On day 14, the *metaball* was located in QIII, showing feelings such as frustration, annoyance, sadness and tiredness.

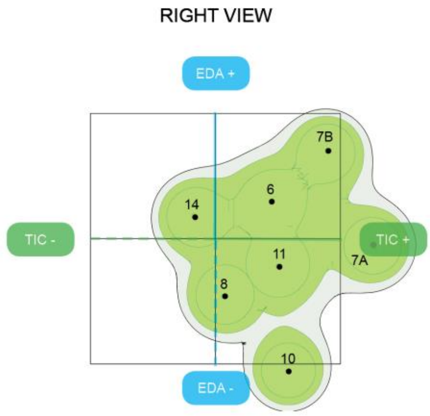
Most of the *metaball*s which were associated with the datasets from days 6, 7, 8, 11 and 14 coalesced with a multiplier factor of 1.5, creating a volume located in the conjunction of Quadrant I and VII, indicating that the predominant feelings that Participant J might feel under Green were feelings that go from *excitement to anxiety, stress, anger and overstimulation*.

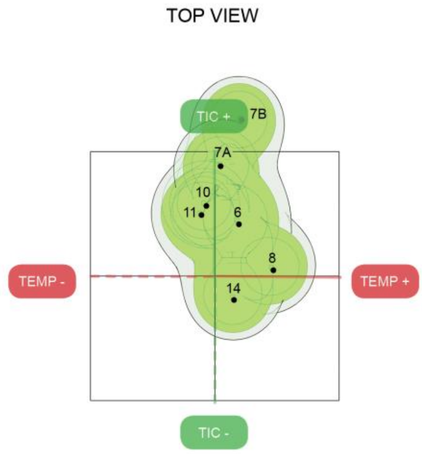
The *metaball* from day 10 needed a multiplier factor of 2.00 to merge with the rest of *metaball*s.

The volume created with the 1.5 multiplier factor, composed by the majority of the datasets collected and which expanded between Quadrant I and VII, indicated that the results observed under Green might be consistent. Due to the location of the meatball in the intersection between positive and negative quadrants, feelings under Green might be neutral and standard. Therefore, these results might shed light on the mood of Participant J under Green. The mood might be predicted, and this information might be used for future purposes.

Overall, five out of seven days the feelings of Participant J observed under Green were considered as positive feelings, and two out of seven days the participant felt negative emotions under Green. Consequently, results shown in Figure 7.32 indicated that, even though the meatball was considered neutral, it had a slight tendency to positive feelings under Green exposures.







PARTICIPANT J - GREEN LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4				
5				
6	I	0.37	36.17	4.80
7 A (*)	I	0.28	36.20	8.89
7 B	I	0.47	36.00	7.02
8	II	0.18	36.52	2.88
9				
10	VIII	0.03	35.84	5.46
11	VIII	0.24	35.80	5.06
12				
13				
14	III	0.34	36.13	1.69

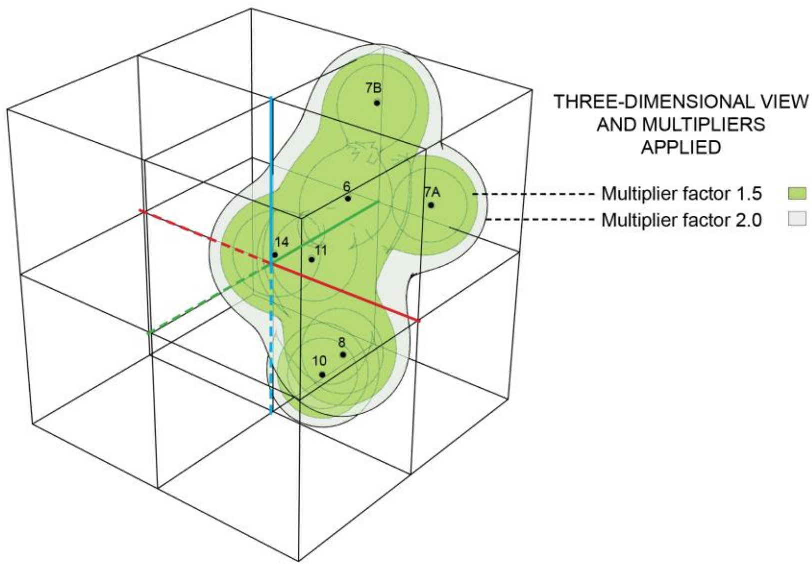


Figure 7. 32. 3D Mood Box of Participant J under Green light conditions (displayed in colour green for a better comprehension) for Analysis A. This group of images presents the data from the physiological signals combined of Participant J under Green light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Red:

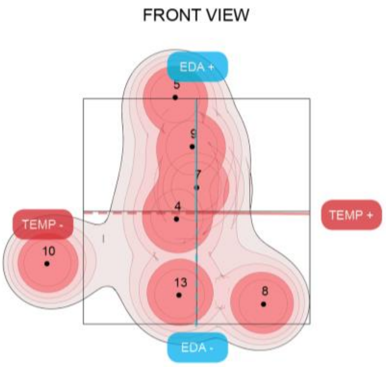
Participant J was exposed to Red, with a successful collection of the three complementary types of data, seven times. The distribution of the points shown in Figures 7.33, referring to the 3D Mood Box of Participant J felt under Red was the following:

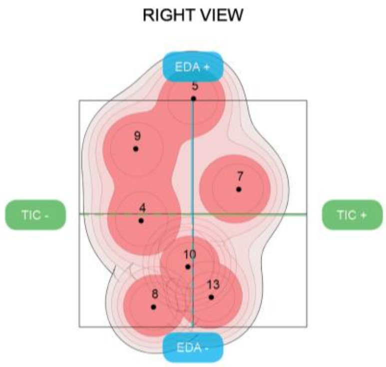
- On day 4, the *metaball* was located between QV and QVI, showing feelings between alertness, mental workload or distraction.
- On day 5, the *metaball* was located between QV and QVII, showing feelings between alertness and mental workload distraction and anxiety, anger and overstimulation.
- On day 7, the *metaball* was located between QI and QVII, showing feelings between excitement and anxiety, stress, anger and overstimulation. This result indicates that the feeling that the participant might have felt was neutral and standard.
- On day 8, the *metaball* was located in QIV, showing feelings such as relaxation.
- On day 9, the *metaball* was located in QV, showing feelings such as alertness and mental workload. On day 9, the Red exposure lasted less than 30 seconds because the participant wanted to change the colour of the light.
- On day 10, the *metaball* was located between QVI and QVIII, showing feelings between distraction and frustration, annoyance, sadness and tiredness.
- Similarly, on day 13, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.

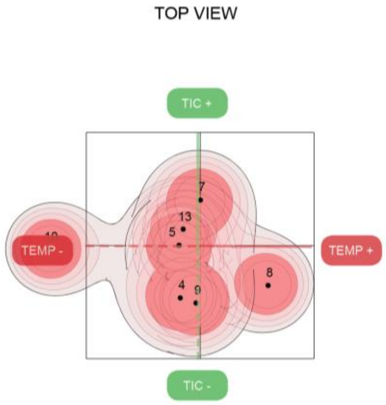
The datasets from days 4, 5, and 9 coalesced with a multiplier factor of 1.5, creating a volume located in the Quadrant V, indicating that the most common feeling that Participant J might feel under Red was alertness or mental workload or mental workload. Three of the other remaining four *metaball*s needed a multiplier factor of 2.00 to merge with volume. The *metaball* from day 10, however, needed a multiplier factor of 3.00 to merge with the rest of the *metaball*s.

The volume created with the 1.5 multiplier factor was composed by only three out of seven of the datasets collected, therefore results were not consistent enough because it was composed by a minority of the *metaballs*. When most of the *metaball*s coalesce with the multiplier factor of 2.00, the volume extends too much around all the quadrants, and there was no definite feeling the participant might have been feeling under Red so the mood might not be predicted.

Overall, on one out of seven days the feelings of Participant J observed under Red were considered as positive feelings, one out of seven times the feelings that the participant felt were considered neutral, one out of seven days the participant was mainly concentrated or alert, and four out of seven days the participant felt negative emotions under Red. Consequently, results shown in Figure 7.33 indicated that the participant felt mainly negative feelings under Red exposures.







PARTICIPANT J - RED LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4	V-VI	0.28	35.73	0.24
5	V-VII	0.55	35.71	2.55
6				
7	I-VII	0.35	35.95	4.55
8	IV	0.09	36.69	0.81
9 (*)	V	0.44	35.90	0.00
10	VI-VIII	0.18	34.30	2.39
11				
12				
13	VIII	0.11	35.76	3.30
14				

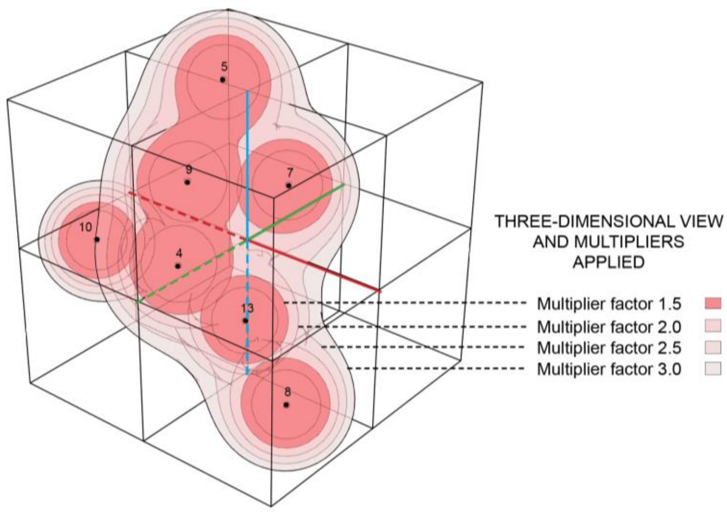


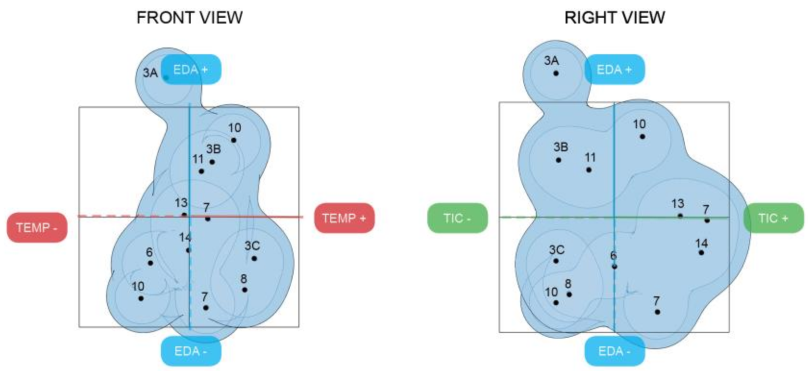
Figure 7. 33. 3D Mood Box of Participant J under Red light conditions (displayed in colour red for a better comprehension) for Analysis A. This group of images presents the data from the physiological signals combined of Participant J under Red light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

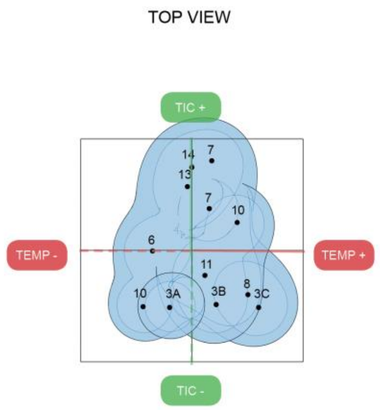
Blue:

Participant J was exposed to Blue, with a successful collection of the three complementary types of data, twelve times. The distribution of the points shown in Figures 7.34, referring to the 3D Mood Box of Participant J felt under Blue was the following:

- On day 3, Participant J was exposed to Blue three times. The first time, the *metaball* was located in QV, showing feelings such as alertness and concentration. The second time, the *metaball* was located in QIII, showing feelings such as happiness and amusement. These two times, however, the duration of the exposure was less than 30 seconds and might not be as significant as the others, comparatively speaking. The third time, the *metaball* was located in QIV, showing feelings such as relaxation.
- On day 6, the *metaball* was located between QVI and QVIII, showing feelings between distraction and frustration, annoyance, sadness and tiredness.
- On day 7, Participant J was exposed to Blue two times, both times, the *metaball* was located in QII, showing feelings such as pleasure and interest. The first time, however, the duration of the exposure was less than 30 seconds and might not be as significant as the others, comparatively speaking. Nevertheless, the results obtained during both light exposures were consistent, indicating that, in this case, the length of the exposure was not essential.
- On day 8, the *metaball* was located in QIV, showing feelings such as relaxation.
- On day 10, Participant J was exposed to Blue two times. The first time, the *metaball* was located in QI, showing feelings such as excitement. The second time, the *metaball* was located in QVI, showing feelings such as distraction. The first time, however, the duration of the exposure was less than 30 seconds and might not be as significant as the others, comparatively speaking.
- On day 11, the *metaball* was located in QIII, showing feelings such as happiness. However, the light exposure was altered. The hue varied and results might not be as significant as others, comparatively speaking.
- On day 13, the *metaball* was located in QVII, showing feelings such as anxiety, anger and overstimulation.
- On day 14, the *metaball* was located between QII and QVIII, showing feelings between pleasure and interest and frustration, annoyance, sadness and tiredness. This result indicates that the feeling that the participant might have felt was neutral.

All the *metaball*s collected under Blue coalesced with a multiplier factor of 1.5, creating a significant volume located in the conjunction of all the quadrants. For this reason, even though in this case, many samples were collected, the volume does not indicate a predominant feeling that Participant J might feel under Blue.





PARTICIPANT J - BLUE LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
3 A (*)	V	0.61	35.70	0.00
3 B (*)	III	0.42	36.23	0.12
3 C	IV	0.20	36.70	0.00
4				
5				
6	VI-VIII	0.19	35.51	2.52
7 A (*)	II	0.09	36.15	4.40
7 B	II	0.29	36.17	6.55
8	IV	0.13	36.58	0.56
9				
10 A(*)	I	0.11	35.40	0.00
10 B	VI	0.47	36.46	3.78
11 (+)	III	0.40	36.10	1.42
12				
13	VII	0.30	35.90	5.40
14	II-VIII	0.22	35.95	6.30

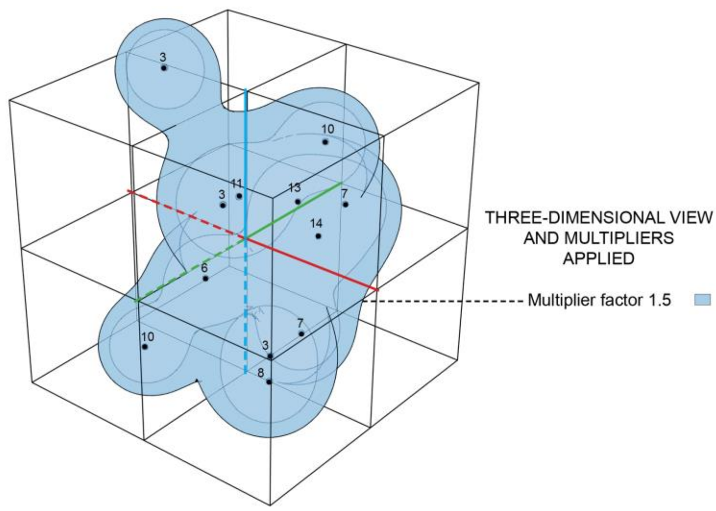


Figure 7. 34. 3D Mood Box of Participant J under Blue light conditions (displayed in colour blue for a better comprehension) for Analysis A. This group of images presents the data from the physiological signals combined of Participant J under Blue light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Unfortunately, even though the results seem consistent, the specific mood might not be predicted. However, results show that the volume, even though it was massive and extends around all the quadrants, was more predominant in the quadrants which were associated with positive feelings.

Overall, seven out of eleven days the feelings of Participant J observed under Blue were considered as positive feelings, one out of eleven times, the participant felt mainly concentrated, one out of eleven times, the participant felt neutral feelings, and three out of eleven days the participant felt negative emotions under Blue. Consequently, results shown in Figure 7.34 indicated that the participant felt more positive feelings than negative feelings under Blue exposures.

Analysis B:

When removing from the dataset the days which could contain erroneous information due to the duration and the light properties, the origin point [0,0,0] changed slightly but the results obtained on the mood analysis under White, Fluorescent Light and Yellow remained the same. However, results obtained under Green, Red and Blue experienced few changes that will be explained below:

Green:

Participant J was exposed to Green, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.35, referring to the 3D Mood Box of Participant J felt under Green was very similar to the one obtained with the light exposure of day 7 which lasted less than 30 seconds. The distribution was the following:

- Two out of seven times, on days 6 and 7, the *metaball* was located in QI, showing feelings such as excitement.
- On day 8, the *metaball* was located very close to QII, showing feelins such as relief.
- Two out of seven times, on days 10 and 11, the *metaball* was located in QVIII, showing feelings such as anxiety, stress, anger and overstimulation. However, both days were very close to the positive quadrants, showing a more positive tendency than a negative tendency.
- On day 14, the *metaball* was located in QIII, showing feelings such as frustration, annoyance, sadness and tiredness.

Most of the *metaball*s which were associated with the datasets from days 6, 7, 8, 11 and 14 coalesced with a multiplier factor of 1.5, creating a volume located in the conjunction of Quadrant I and VII, indicating that the predominant feelings that Participant J might feel under Green were feelings that go from *excitement* to stress. Due to the location of the meatball, feelings should be considered as neutral with a prevalence of positive feelings.

Again, the *metaball* from day 10 needed a multiplier factor of 2.00 to merge with the rest of *metaball*s.

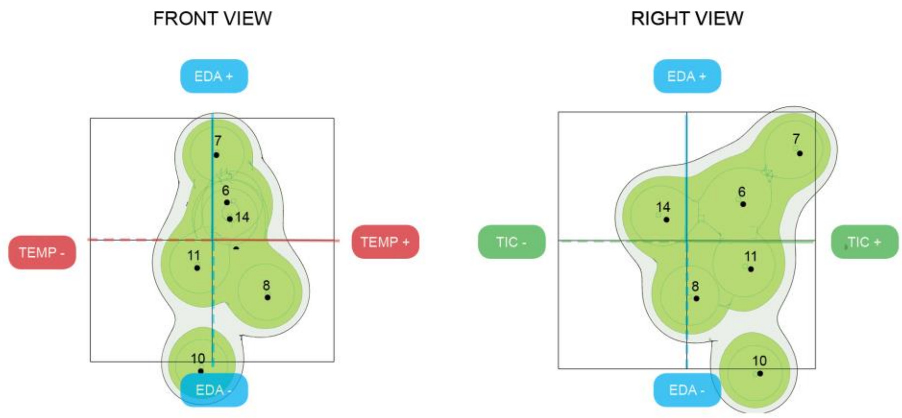
The volume created with the 1.5 multiplier factor, composed by the majority of the datasets collected and which expanded between Quadrant I and VII, indicated that the results observed under Green might be consistent. Therefore, these results might shed light on the mood of

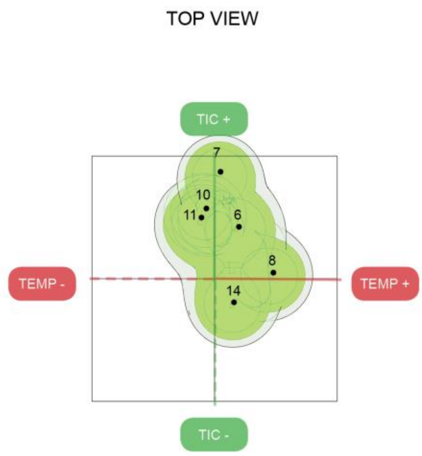
Participant J under Green. The mood might be predicted, and this information might be used for future purposes.

Overall, four out of six days the feelings of Participant J observed under Green were considered as positive feelings, and two out of six days the participant felt neutral/negative emotions under Green. Consequently, results shown in Figure 7.35 indicated that the participant felt mainly positive feelings under Green exposures.

Comparison between Analysis A and Analysis B:

Removing the light exposure from day 7 which lasted less than 30 seconds did not alter the overall meaning of the mood of Participant J observed under Green conditions. Even though the light exposure lasted less than 30 seconds, emotional results during the short exposure were consistent with the results obtained from longer exposures under Green. In other words, in this case in particular, the duration of the exposure did not have a strong impact on the results.





PARTICIPANT J - GREEN LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4				
5				
6	I	0.37	36.17	4.80
7 A (*)	-	-	-	-
7 B	I	0.47	36.00	7.02
8	II	0.18	36.52	2.88
9				
10	VIII	0.03	35.84	5.46
11	VIII	0.24	35.80	5.06
12				
13				
14	III	0.34	36.13	1.69

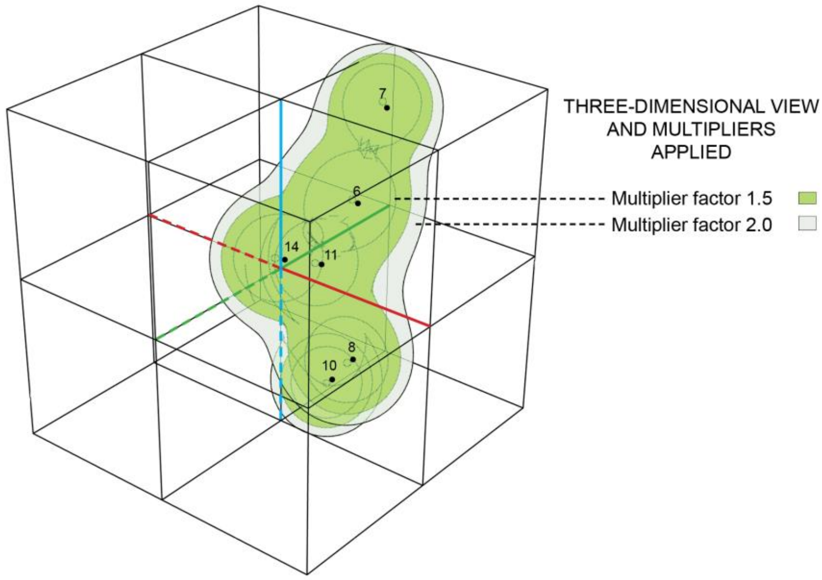


Figure 7. 35. 3D Mood Box of Participant J under Green light conditions (displayed in colour green for a better comprehension) for Analysis B. This group of images presents the data from the physiological signals combined of Participant J under Green light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Red:

Participant J was exposed to Red, with a successful collection of the three complementary types of data, six times. The distribution of the points shown in Figures 7.36, referring to the 3D Mood Box of Participant J felt under Red was very similar to the one obtained with the light exposure of day 9 which lasted less than 30 seconds. The distribution was the following:

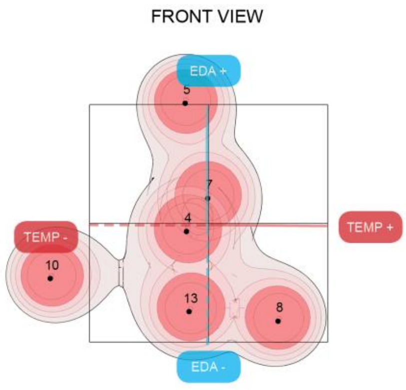
- On day 4, the *metaball* was located between QV and QVI, showing feelings between alertness and mental workload distraction.
- On day 5, the *metaball* was located between QV and QVII, showing feelings between alertness and mental workload distraction and anxiety, stress, anger and overstimulation.
- On day 7, the *metaball* was located between QI and QVII, showing feelings between excitement and anxiety, stress, anger and overstimulation. This result indicates that the feeling that the participant might have felt was neutral and standard.
- On day 8, the *metaball* was located in QIV, showing feelings such as relaxation and relief.
- On day 10, the *metaball* was located between QVI and QVIII, showing feelings between distraction and frustration, annoyance, sadness and tiredness.
- Similarly, on day 13, the *metaball* was located in QVIII, showing feelings such as frustration, annoyance, sadness and tiredness.

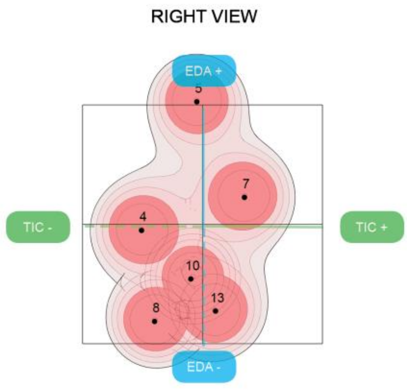
In this case, after removing the dataset of day 9 because of its short duration, none of the observed datasets from Participant J obtained from Red exposures merged under a multiplier factor of 1.5 or less. Therefore, no volume was created between the *metaball*s because all the spheres were dispersed in the 3D Mood Box.

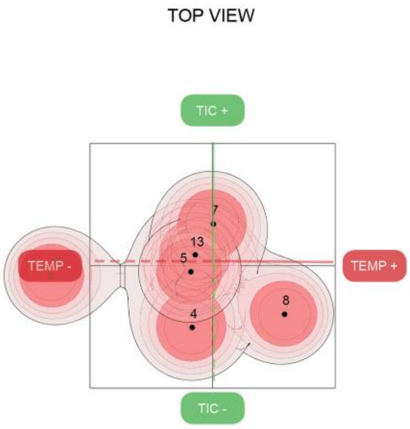
The *metaball*s needed a multiplier factor of 2.00 or 3.00 to merge.

Therefore, these results indicate, that the specific mood of Participant J under Red might not be consistent and, thus, the mood under Red could not be predicted.

Overall, one out of six days the feelings of Participant J observed under Red were considered as positive feelings, and five out of six days the participant felt negative emotions under Red. Consequently, results shown in Figure 7.36 indicate that the participant felt mainly negative feelings under the Red exposures.







PARTICIPANT J - RED LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
2				
3				
4	V-VI	0.28	35.73	0.24
5	V-VII	0.55	35.71	2.55
6				
7	I-VII	0.35	35.95	4.55
8	IV	0.09	36.69	0.81
9 (*)	-	-	-	-
10	VI-VIII	0.18	34.30	2.39
11				
12				
13	VIII	0.11	35.76	3.30
14				

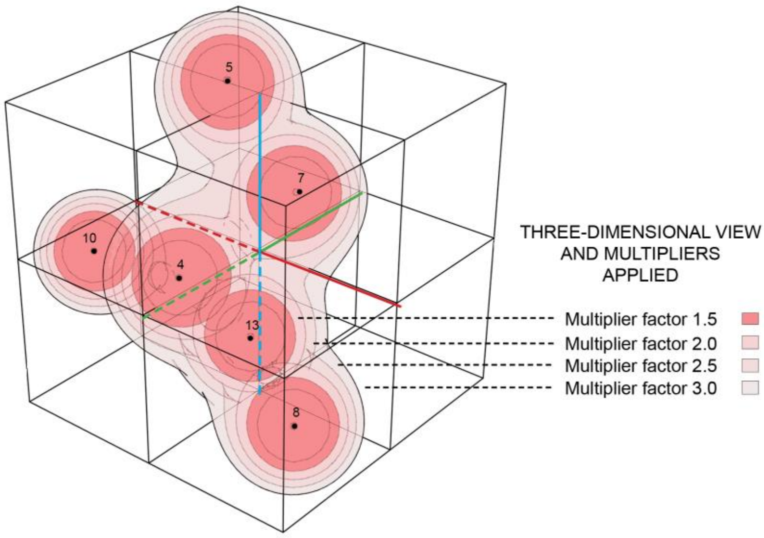


Figure 7. 36. 3D Mood Box of Participant J under Red light conditions (displayed in colour red for a better comprehension) for Analysis B. This group of images presents the data from the physiological signals combined of Participant J under Red light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Comparison between Analysis A and Analysis B:

Removing the light exposure from day 9 which lasted less than 30 seconds altered the overall meaning of the mood of Participant J observed under Red conditions.

The light exposure of day 9 helped to create a solid volume when a multiplier of 1.5 was applied. As the dataset of day 9 coalesced with the spheres created on day 4 and 5, the volume showed an apparent consistency, although the rest of the metaballs were independent and only coalesced when increased by 3.0.

However, when removing the dataset from day 9, all the metaballs became independent and did not coalesce unless a multiplier of 3 was applied. These new results suggest that there was no consistency in any of the datasets of the Participant J under Red but that the majority of the days he felt mainly negative emotions.

This fact indicated that the duration of the exposure impacted on the results and that shorter exposures could be misleading.

These new results align better with the reactions and behaviour of Participant J observed under Red conditions, as he presented aggressive behaviour and demanded a change of the light many times the Red was on.

Blue:

Participant J was exposed to Blue, with a successful collection of the three complementary types of data, seven times. The distribution of the points shown in Figures 7.37, referring to the 3D Mood Box of Participant J felt under Blue was the following:

- On day 3, the *metaball* was located in QIV, showing feelings such as relief and relaxation.
- On day 6, the *metaball* was located between QVI and QVIII, showing feelings between distraction and frustration, annoyance, sadness and tiredness.
- On day 7, the *metaball* was located in QII, showing feelings such as contentment, pleasure and interest.
- On day 10, the *metaball* was located in QI, showing feelings such as excitement.
- On day 13, the *metaball* was located between QI and QVII, showing feelings between excitement and anxiety and overstimulation.
- On day 14, the *metaball* was located between QII and QVIII, showing feelings between contentment, pleasure and interest and frustration, annoyance, sadness and tiredness. This result indicates that the feeling that the participant might have felt was neutral and standard.

The *metaball*s collected under Blue coalesced with a multiplier factor of 1.5 in two groups, creating two significant volumes. One of them is located in the conjunction of QI, II and VI showing feelings such as excitement, interest and distraction. The second volume is located in Quadrant IV, showing feelings such as relaxation and relief. Both volumes coalesced when the metaballs increased by 2.00. Therefore, results of Analysis B are consistent and show that Participant J felt mainly positive feelings under Blue.

Overall, five or six out of seven days the feelings of Participant J observed under Blue were considered as positive feelings and one out of seven times the participant felt mainly negative emotions under Blue. Consequently, results shown in Figure 7.37 indicated that the participant felt more positive feelings than negative feelings under Blue exposures.

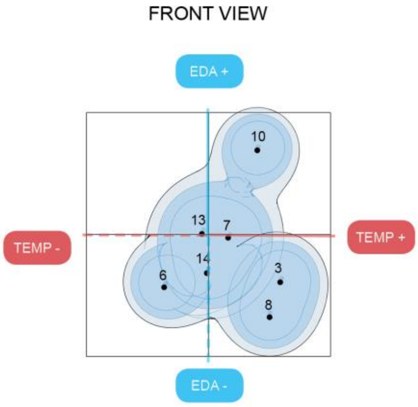
Comparison between Analysis A and Analysis B:

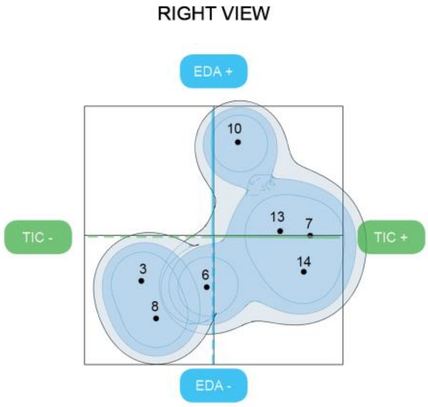
Removing the light exposures from days 3, 7 and 10 which lasted less than 30 seconds and the light exposure of day 11 with a different hue of the light, altered the overall meaning of the mood of Participant J observed under Blue conditions.

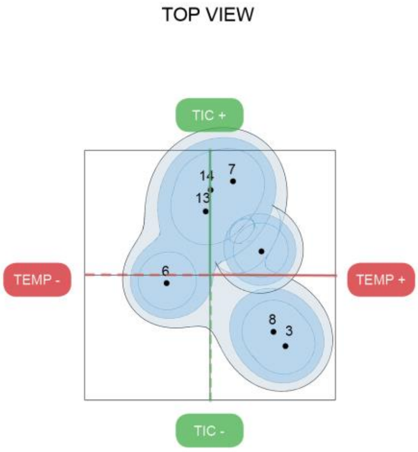
The removed light exposures helped to create a significant solid volume when a multiplier of 1.5 was applied that expanded around all the quadrants. However, when these exposures were removed from the 3D Mood Box, two solid volumes were created in the positive quadrants. Both volumes merged with a multiplier factor of 2.0.

This fact indicated that the duration of the exposure and the properties of the light impacted the results and that these exposures could be misleading.

These new results align better with the reactions and behaviour of Participant J observed under Blue conditions, as he demanded to experience Blue many times during the case study and seemed more communicative when Blue was on. Although distraction can be considered as a negative feeling when concentration doing tasks is necessary, distraction can also indicate that something amuses the participant and attract their attention. This exactly what happened to Participant J many times Blue was on. Therefore, as Blue might distract and amuse the participant, this light should not be used when concentration is required, but it can be very useful to improve the mood of the participant when he feels anxious or overstimulated.







PARTICIPANT J - BLUE LED LIGHT				
DAY	Q	tEDA	Temp	RPM tics
3 A (*)	-	-	-	-
3 B (*)	-	-	-	-
3 C	IV	0.20	36.70	0.00
4				
5				
6	VI-VIII	0.19	35.51	2.52
7 A (*)	-	-	-	-
7 B	II	0.29	36.17	6.55
8	IV	0.13	36.58	0.56
9				
10 A(*)	-	-	-	-
10 B	I	0.47	36.46	3.78
11 (+)	-	-	-	-
12				
13	I-VII	0.30	35.90	5.40
14	II-VIII	0.22	35.95	6.30

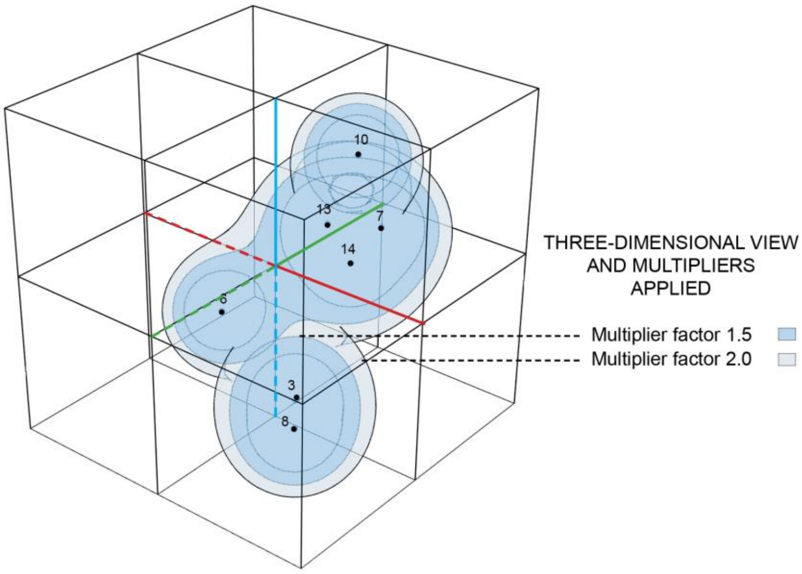


Figure 7. 37. 3D Mood Box of Participant J under Blue light conditions (displayed in colour blue for a better comprehension) for Analysis B. This group of images presents the data from the physiological signals combined of Participant J under Blue light conditions. FRONT, RIGHT and TOP VIEW show the projections of the axonometry. Every metaball is associated to a number, which indicates the day of the dataset was collected. The quantitative data of every day is specified in the table.

Conclusions for Participant J:

The characteristics of the different volumes created under the different light conditions indicated that the different types of the light do impact differently in the mood of Participant J.

Comparison between White and Fluorescent. The importance of the source of the light:

Figure 7.38 shows the results obtained from White LED exposures and Fluorescent light exposures for Participant J. Results indicate that the influence of the White, and the Fluorescent light affected the mood of Participant J differently.

Results show that both lights coalesced with a significant multiplier factor of 1.5, indicating consistency in the results. On the one hand, results of White show that the *metaballs* coalesced with a significant multiplier factor of 1.5, but the location of the metaballs indicate that there is no prevalence of positive or negative feelings. However, results indicate that on almost half of the occasions, the participant was concentrated under White light. On the other hand, results under Fluorescent light were consistent and indicated that half of the *metaballs* coalesced with a multiplier factor of 1.5, showing a prevalence of positive feelings of Quadrant III such as happiness.

These findings indicate that Participant J showed a difference in the mood regarding the source of the light. While feelings under White were unpredictable, results under Fluorescent light, seemed to induce positive mood in the participant.

These findings indicate that Fluorescent could be more suitable than White for Participant J.

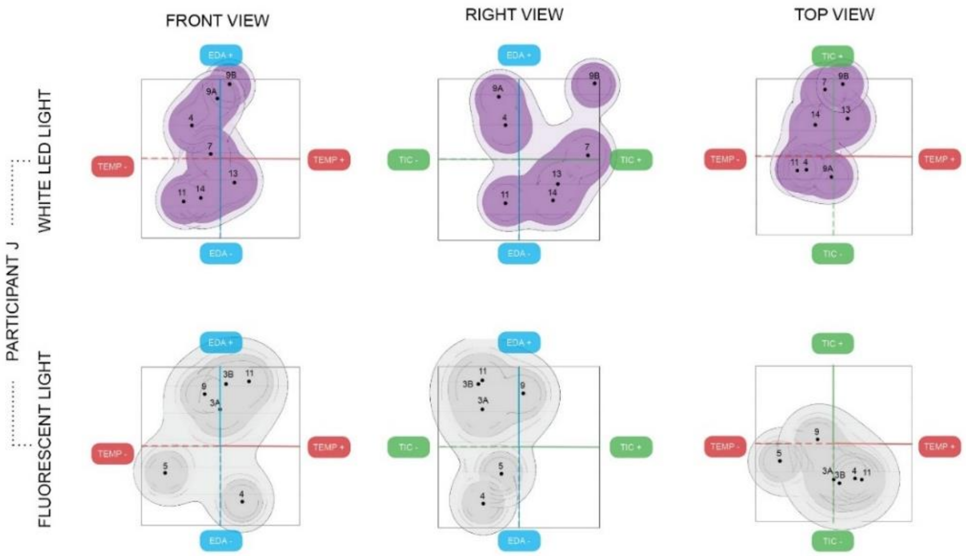


Figure 7. 38. 3D Mood Box of Participant J under White and Fluorescent Light conditions (displayed in colour purple and grey, respectively). Every metaball is associated with a number, which indicates the day of the dataset was collected.

The influence of the colour of the light on the participant's mood:

As the comparison between Analysis A and Analysis B showed that the light exposures which lasted less than 30 seconds could impact the results giving misleading information, only the results obtained on the Analysis B were taken into consideration when comparing the influence of the colour of the light on the participant's mood.

Figure 7.39 shows the results obtained under different LED colour lights for Participant J. Results obtained under the different coloured lights are consistent and coalesced with a multiplier factor of 1.5 creating different volumes and shapes for every colour. These results indicate that every colour of the light induced different feelings, and this information could be used in the environment to obtain different outcomes.

Results of Yellow, Green and Blue exposures show that these colours of the light seemed to induce positive feelings to Participant J. First, Yellow seemed to stimulate feelings such as happiness, relaxation and relief. Secondly, positive feelings observed under Green were located in QI and were positive feelings such as excitement. Third, Blue seems to stimulate positive feelings from QI and QIV such as excitement, joy and relax and relief. This finding also corresponds to the fact that Participant J wanted to change the colour of the light to Blue many times.

Results also show that Participant J felt mainly negative feelings under Red exposures.

Considering the results mentioned, in order to improve the well-being and quality of life of Participant J in the environment, Green and Blue could be used to increase his happiness levels. Blue and Yellow could be the more suitable light to calm him if he were feeling stressed, although Yellow might be more unpredictable than Blue, and Red should be avoided as it might provoke annoyance and frustration.

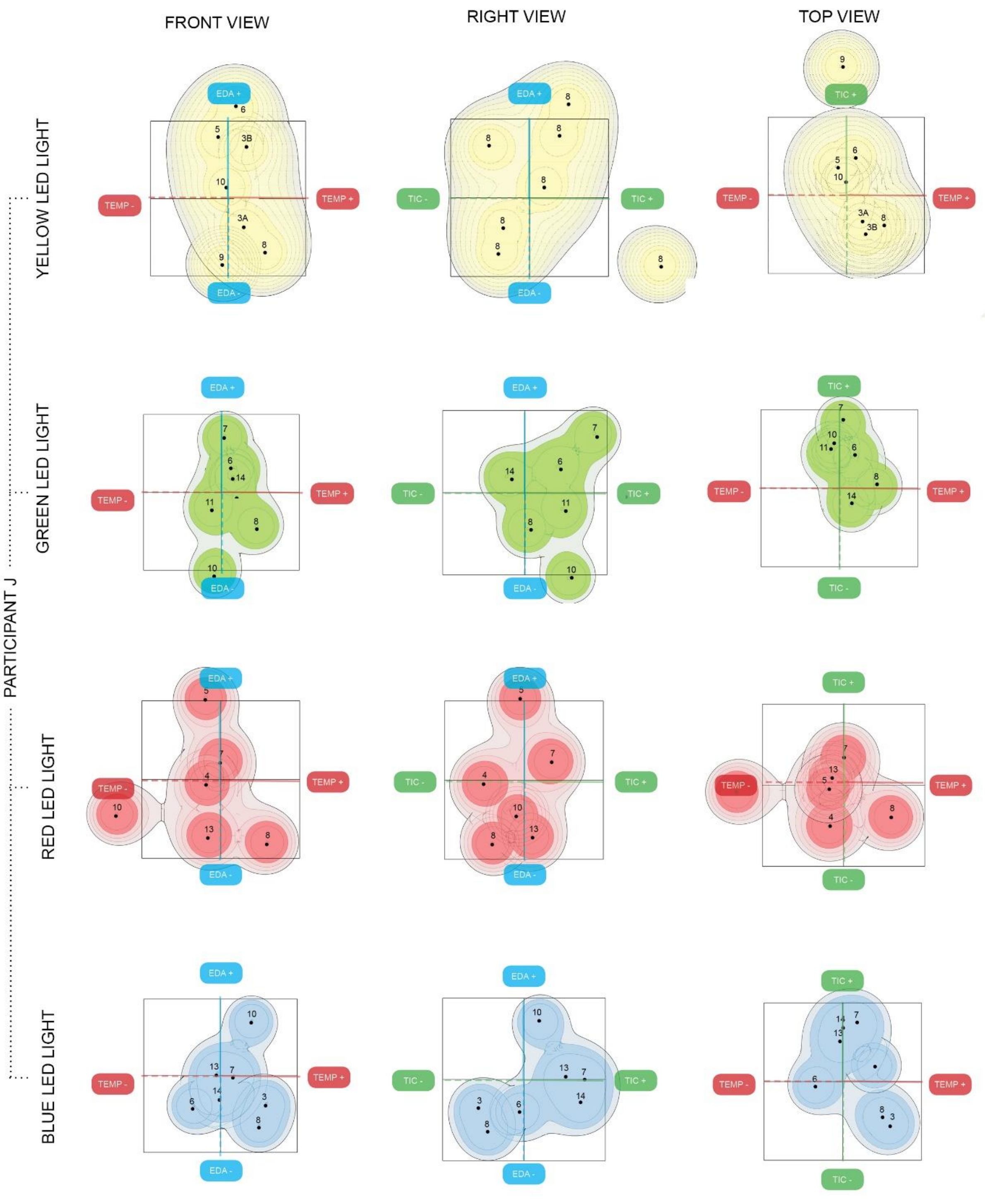


Figure 7. 39. 3D Mood Box of Participant J under Yellow, Green, Red and Blue conditions (displayed in colour yellow, green, red and blue, respectively). Every metaball is associated with a number, which indicates the day of the dataset was collected.

7.3.5. Comparison between participants and colours

White

Figure 7.40 shows the results obtained for each participant under White to facilitate the comparison between participants. As can be seen in Figure 7.40, the shapes obtained with the metaballs are all different for each participant. The different shapes displayed in the figures indicate that the White light might influence differently every participant's mood.

Results of Participant F, Participant FX and Participant H (although his sample was minimal) show that the metaballs did not coalesce with a multiplier factor of 1.5, indicating that the nature of the feeling cannot be predicted in the future. Results of Participant J, however, showed consistency in the results and coalesced with the 1.5 multiplier factor.

Even though the metaballs of most of the participants did not coalesce, results show that White might induce both positive and negative feelings, depending on the participant. Participants F and H present positive feelings when exposed to White, although the specific type of feelings cannot be predicted. Participant FX seemed to have a balance between positive, negative and concentrated emotions under White light. Participant J had a prevalence of negative feelings under White light.

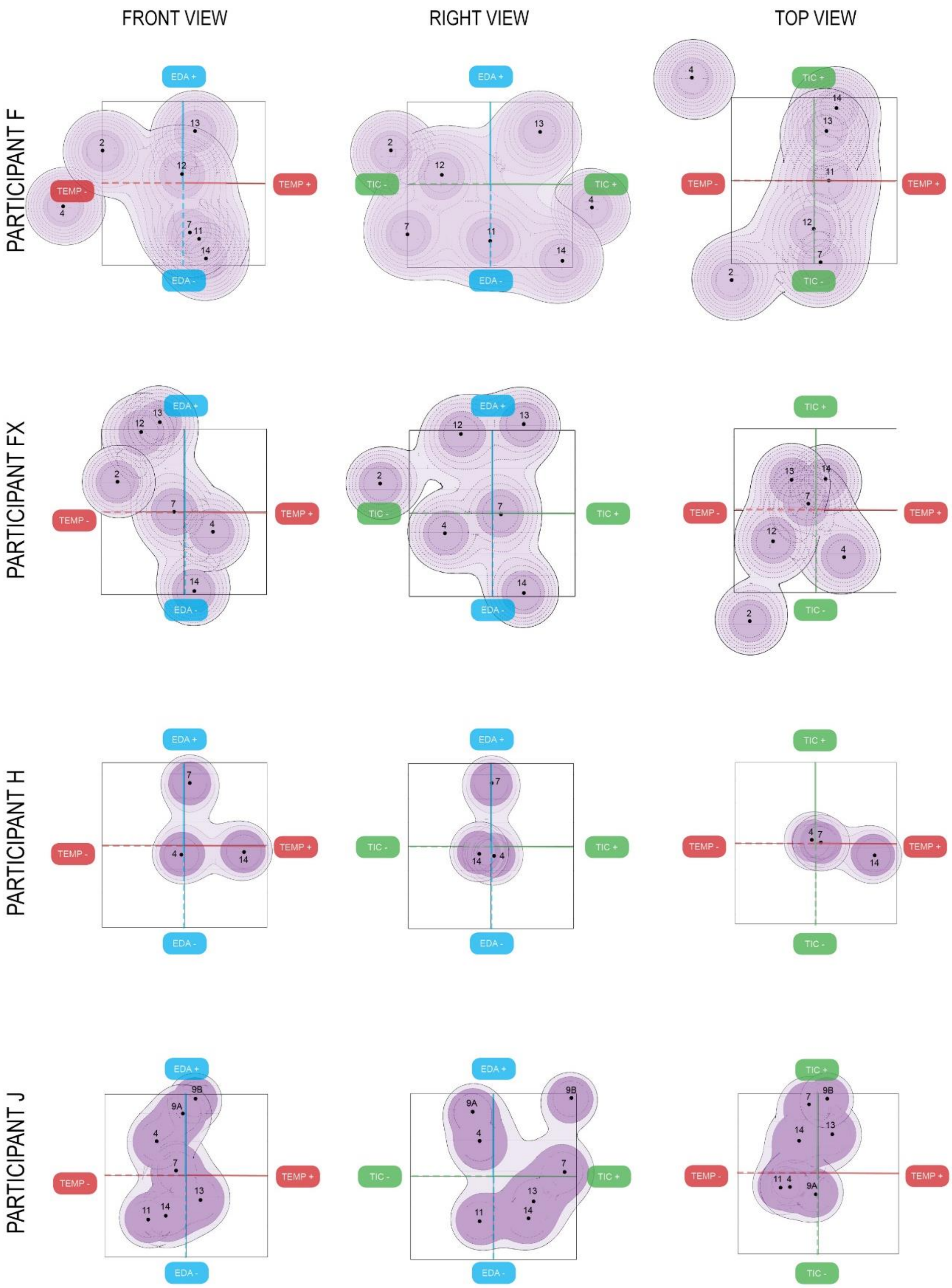


Figure 7. 40. 3D Mood Box of all participants under White conditions (displayed in colour purple). Every metaball is associated with a number, which indicates the day of the dataset was collected.

Fluorescent light

Figure 7.41 shows the results obtained for each participant under Fluorescent light to facilitate the comparison between participants. As can be seen in Figure 7.41, the shapes obtained with the metaballs are all different for each participant. The different shapes displayed in the figures indicate that the Fluorescent light might influence differently every participant's mood.

Results of Participant F show that the metaballs did not coalesce with a multiplier factor of 1.5. Indicating that the nature of the feeling cannot be predicted in the future. Results of Participant FX and Participant J, however, showed consistency in the results and coalesced with the 1.5 multiplier factor. Results of Participant H were not conclusive because of the limited sample.

Even though the metaballs of Participant F did not coalesce, results show that Fluorescent light might induce her mainly positive feelings, although the specific type of feelings cannot be predicted. Participants FX and J present positive feelings when exposed to Fluorescent light as well. However, while Participant FX seemed to experience positive low arousing feelings such as relief and relax (QII and QIV), Participant J seemed to experience positive high arousing feelings such as happiness (QIII and QV). Participant H seemed to have negative emotions (QVII) under Fluorescent light; however, the sample size is too small to see if the results are merely anecdotic.

Positive emotional responses under Fluorescent light from the participants were unexpected, as many testimonies stated that the fluorescent source usually provokes detrimental outcomes on the individuals. However, the results obtained can be a consequence of various factors. On the one hand, the translucent shade used in the lighting system might have offset the effect of the flicker. On the other hand, the bulbs chosen were less intense than the fluorescent source which is used commonly in the school and other public buildings, and this fact might have influenced the intensity of the effect of the flicker. Further research, using more powerful and common fluorescent light systems, should be necessary to determine whether the fluorescent source is detrimental or not for the children.

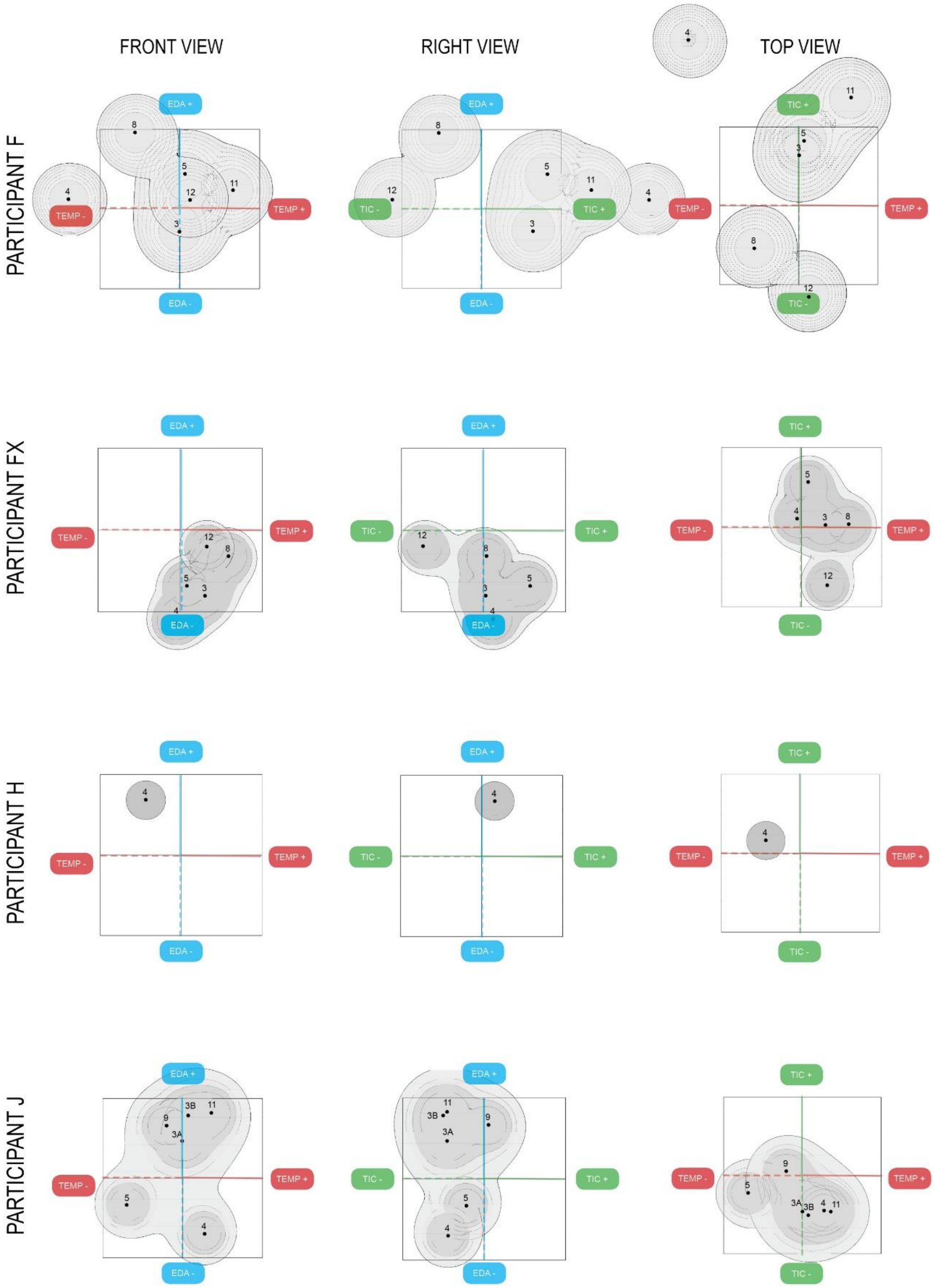


Figure 7. 41. 3D Mood Box of all participants under Fluorescent light conditions (displayed in colour grey) in the 3D Mood Box. Every metaball is associated with a number, which indicates the day of the dataset was collected.

Yellow

Figure 7.42 shows the results obtained for each participant under Yellow to facilitate the comparison between participants. As can be seen in Figure 7.42, the shapes obtained with the metaballs are all different for each participant. The different shapes displayed in the figures indicate that the Yellow might influence differently every participant's mood.

Results of Participant F, Participant FX and Participant J show that the metaballs coalesced with a multiplier factor of 1.5. Indicating that the results were consistent and that the nature of the feeling might be predicted in the future. Results of Participant H did not coalesce and were not conclusive because of the limited sample.

Results of all the participants show that Yellow might induce mainly positive feelings, although the specific type of feelings differs depending on the participant. While Participant F seemed to experience positive high arousing feelings such as happiness (QIII), Participant FX seemed to experience positive low arousing feelings such as relief and relax (QIV and QII), and Participant J seemed to experience positive feelings that might oscillate from happiness to relax (QIII and QIV). Participant H seemed to have positive emotions under Yellow as well; however, the sample size is too small to see a prevalent type of feeling.

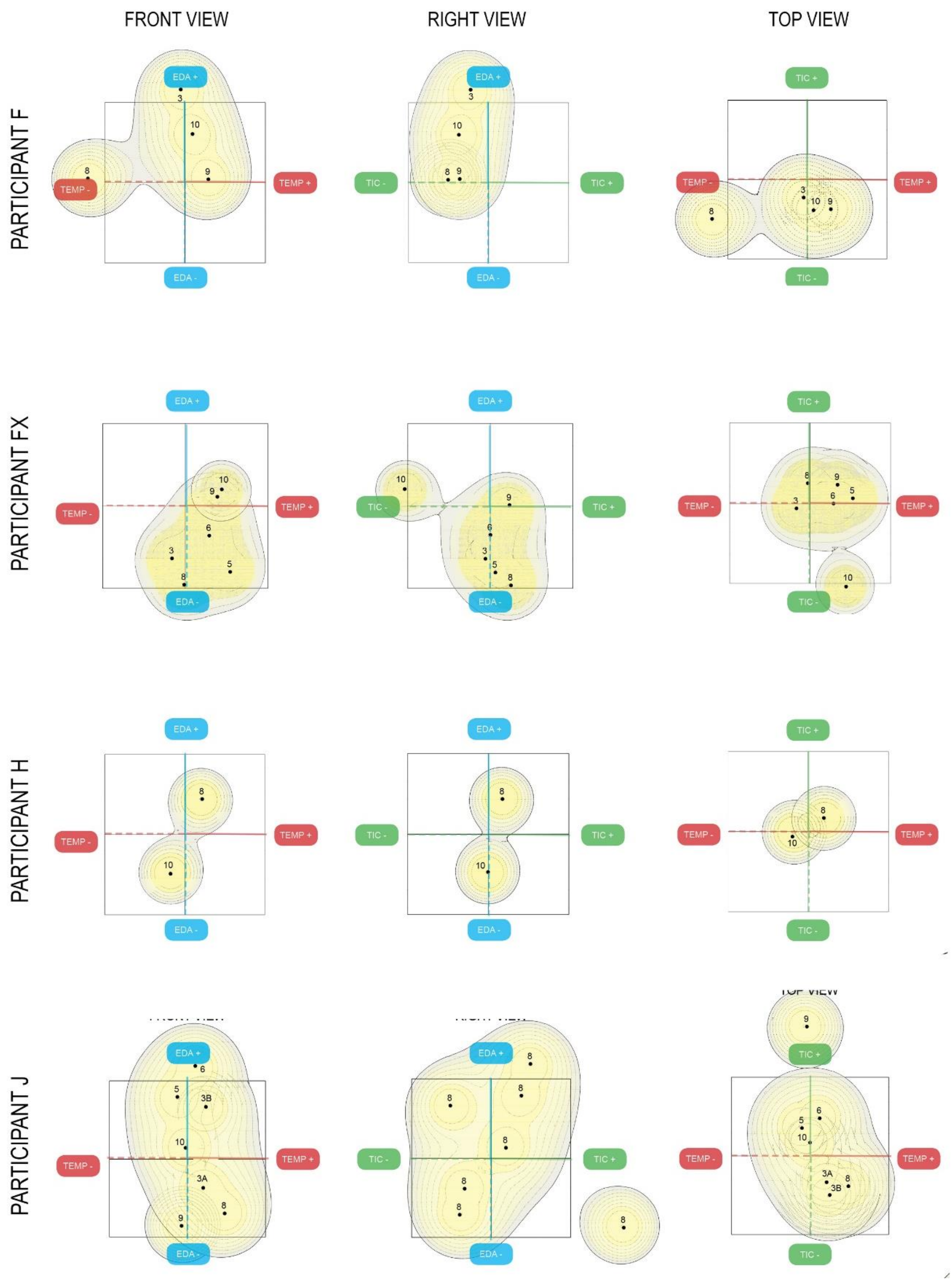


Figure 7. 42. 3D Mood Box of all participants under Yellow conditions (displayed in colour Yellow). Every metaball is associated with a number, which indicates the day of the dataset was collected.

Green

Figure 7.43 shows the results obtained for each participant under Green to facilitate the comparison between participants. As can be seen in Figure 7.43, the shapes obtained with the metaballs are all different for each participant. The different shapes displayed in the figures indicate that the Green might influence differently every participant's mood.

Results of Participant F, Participant FX and Participant J show that the metaballs coalesced with a multiplier factor of 1.5. Indicating that the results were consistent and that the nature of the feeling might be predicted in the future. Results of Participant H did not coalesce and were not conclusive because of the limited sample.

Results of Participant F, Participant H and Participant J show that Green might induce mainly positive feelings, although the specific type of feelings differs depending on the participant. While Participant F seemed to experience all kinds of positive feelings (QII, QIII and QIV), Participant J seemed to experience positive feelings that might oscillate between excitement and relief (QI-QII). Participant H seemed to have positive emotions under Green as well; however, the sample size is too small to see a prevalent type of feeling in his case. Participant FX, however, seemed to have a balance between positive, negative, neutral and concentrated emotions under Green. However, it is possible to observe a small prevalence of negative feelings and alertness or mental workload (QVII and QV).

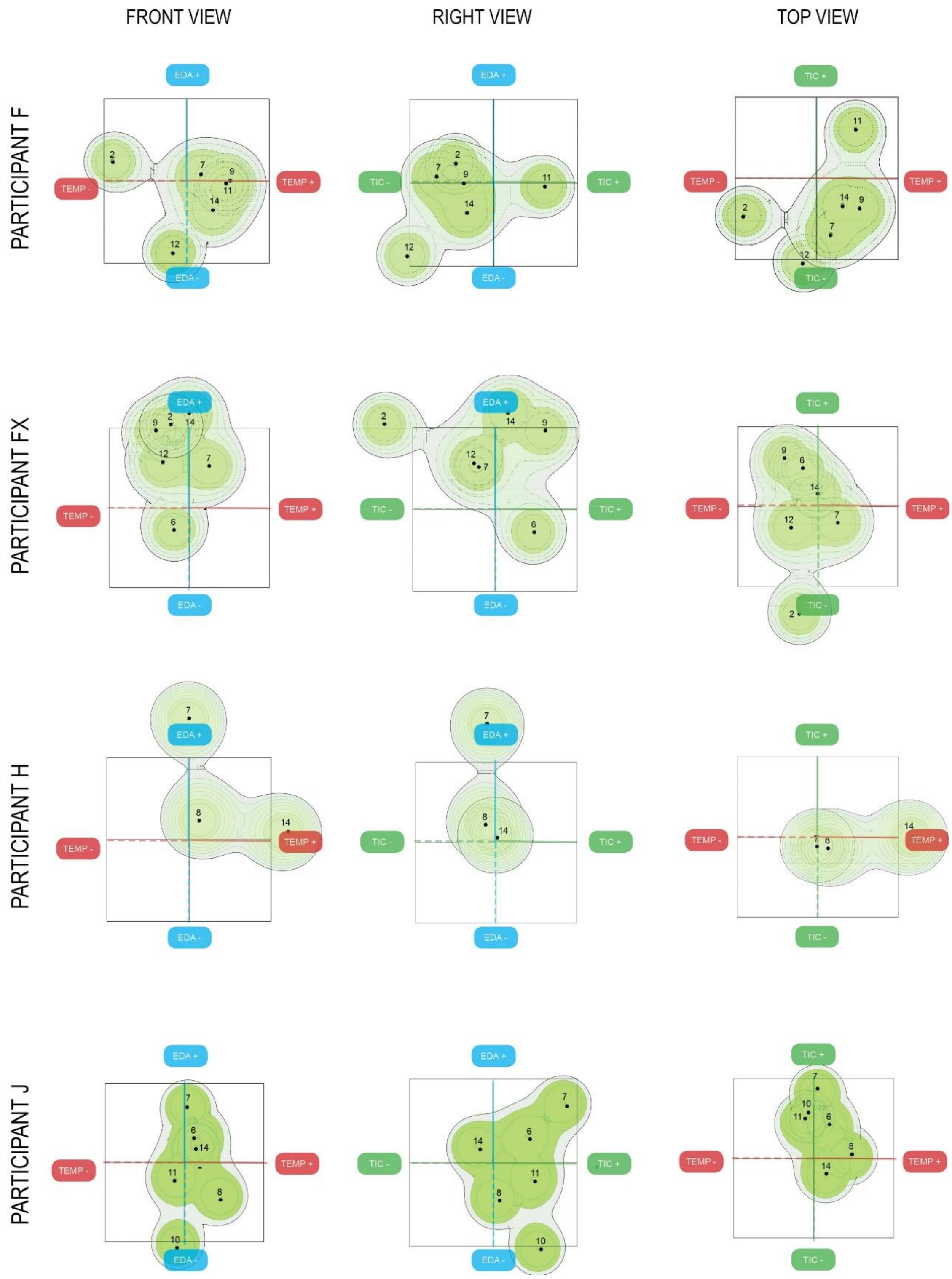


Figure 7. 43. 3D Mood Box of all participants under Green conditions (displayed in colour Green). Every metaball is associated with a number, which indicates the day of the dataset was collected.

Red

Figure 7.44 shows the results obtained for each participant under Red to facilitate the comparison between participants. As can be seen in Figure 7.44, the shapes obtained with the metaballs are all different for each participant. The different shapes displayed in the figures indicate that the Red might influence differently every participant's mood.

Results of Participant F and Participant J show that only half of the metaballs coalesced with a multiplier factor of 1.5. Indicating that the results were consistent partly and that the nature of the feeling might be predicted in the future. However, results of Participant FX and Participant H did not coalesce with a multiplier factor of 1.5, indicating no consistency and that the nature of the feeling cannot be predicted in the future.

Results of Participant F and Participant J show that Red might induce mainly negative feelings and seemed to experience feelings such as annoyance and stress (QVII and QVIII) under Red. Participant H seemed to have both positive and negative emotions under Red; however, the sample size is too small to see a prevalent type of feeling. Participant FX, however, seemed to have positive high arousing feelings (QI and QIII) under Red.

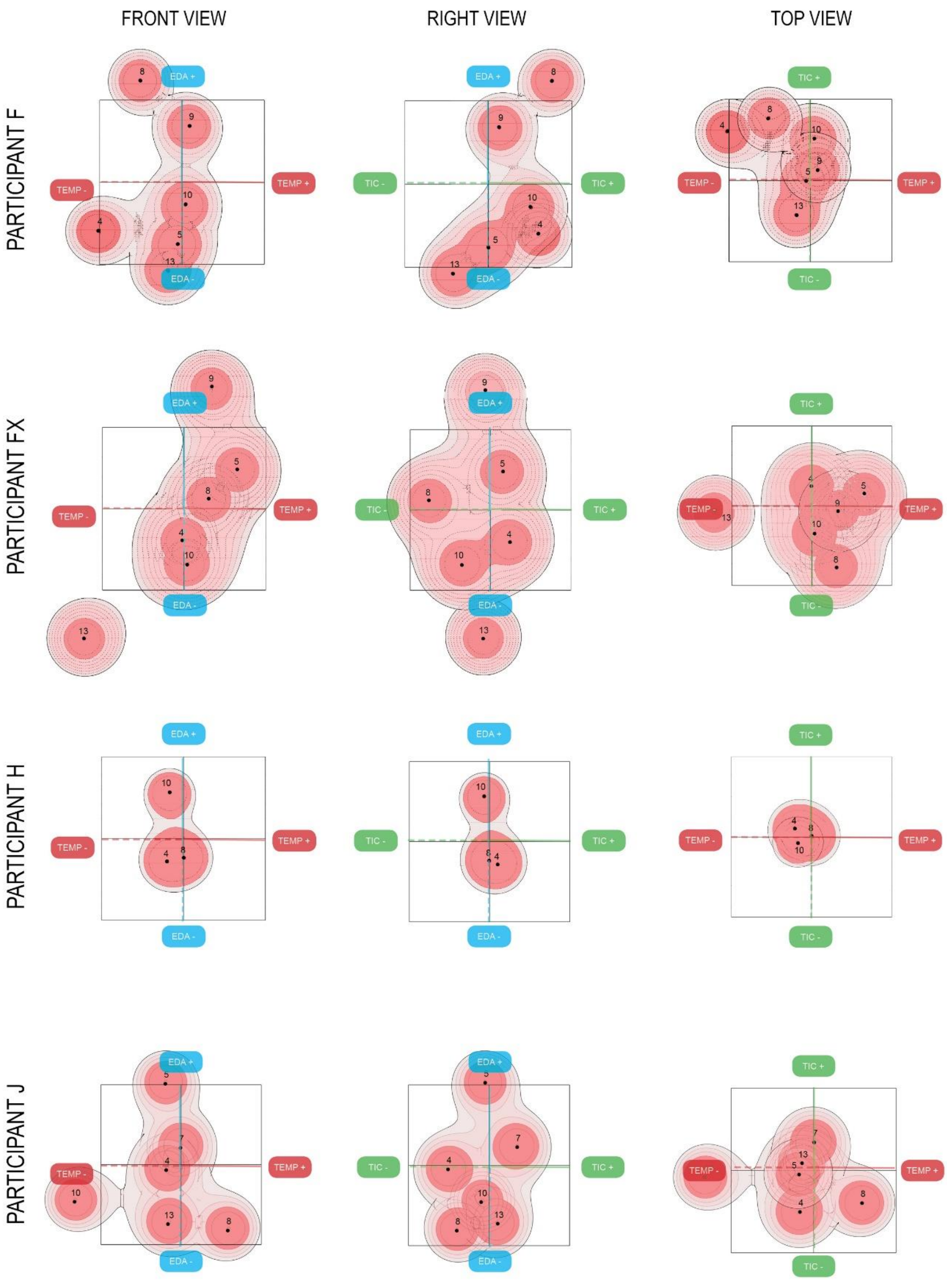


Figure 7. 44. 3D Mood Box of all participants under Red conditions (displayed in colour Red). Every metaball is associated with a number, which indicates the day of the dataset was collected.

Blue:

Figure 7.45 shows the results obtained for each participant under Blue to facilitate the comparison between participants. As can be seen in Figure 7.45, the shapes obtained with the metaballs are all different for each participant. The different shapes displayed in the figures indicate that the Blue might have a different influence on each participant's mood.

Results of Participant F and Participant J show that most of the metaballs coalesced with a multiplier factor of 1.5. Indicating that the results were consistent and that the nature of the feeling might be predicted in the future. Results of Participant FX and Participant H did not coalesce with a multiplier factor of 1.5, indicating no consistency that the nature of the feeling cannot be predicted in the future.

Results of Participant F show that Blue might induce mainly negative feelings and seemed to experience feelings such as annoyance and stress (QVI, QVII and QVIII) under Blue. Results of Participant FX show unpredictable feelings but a strong prevalence of negative feelings. Participant H seemed to have both positive and negative emotions under Blue; however, the sample size is too small to see a prevalent type of feeling. Participant J, however, seemed to have mainly positive feelings which expand around QI, QIV and Q VI showing feelings such as excitement, joy, relax and distraction under Blue.

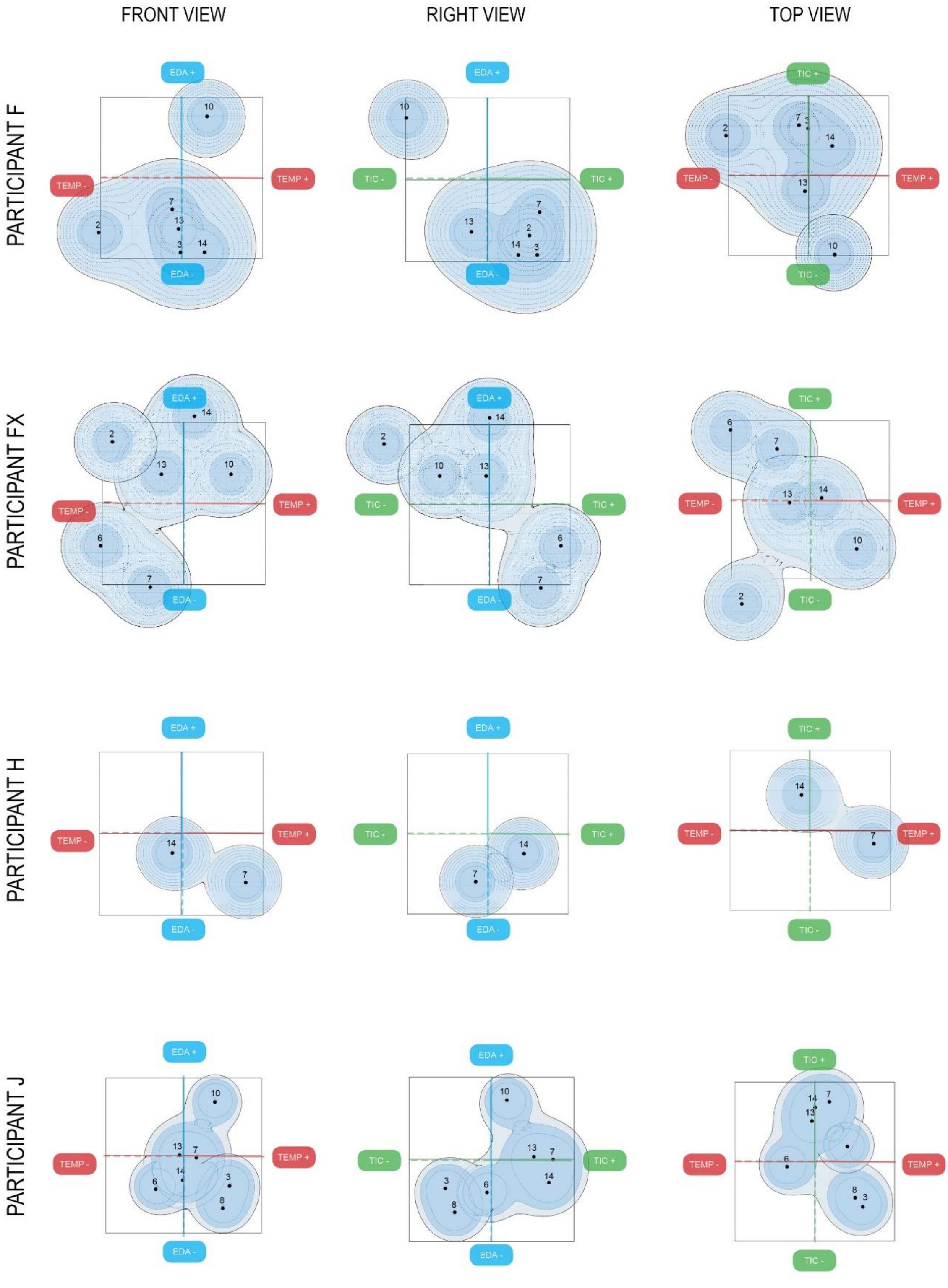


Figure 7. 45. 3D Mood Box of all participants under Blue conditions (displayed in colour Blue). Every metaball is associated with a number, which indicates the day of the dataset was collected.

7.4. Chapter Inference:

One of the biggest challenges of this investigation was interpreting the emotional states of the participants under different light conditions without using questionnaires and subjective information.

However, the literature showed that different physiological signals and behavioural analysis could inform objectively about mood but that the signals might be insufficient when interpreted separately. For this reason, it was proposed to combine EDA, temperature of the tip of the nose, and tic behaviour analysis, aiming at interpreting the emotional states collectively.

The combination of data is introduced in a three-dimensional map designed for this research called the 3D Mood Box. The location of the different datasets indicates the mood the participant might have under a certain light exposure, and consistency of the results suggests how likely it is that the participants could feel the same way in the future, therefore it is expected that the light could be used to achieve different outcomes in the future.

Although some similarities in the tendency of the mood (positive/negative) can be found between the participants under different light conditions, the different and unique shapes and volumes created by the metaballs which coalesced under a multiplier factor of 1.5 for each participant show that interpreting the environment and how it influences in our mood is highly particular to, and characteristic of, each person.

This chapter presented all the results which show the influence that the colour and source of the light might have had in the mood of every participant.

The implications of all the results about the influence of the lights in the physiological signals and behavioural analysis found and described in Chapter Five, and the possible influence of the lights on the mood based on the previous results described in the current chapter will be explained in the following chapter, trying to answer the main questions of the research about the influence of the colour and source of the light, as well as other sub-questions related to the main questions and the methods. The limitations of the method and the experimental method proposed for future work will also be explained in Chapter Eight.

CHAPTER EIGHT - **DISCUSSION**

After seeing the strong impact that the features of the environment, especially colour and light, might have on human beings, one of the first questions laid out in this thesis was whether the findings observed in the literature about the influence of the colour and the light in the mood, behaviour and performance of an individual were generalizable to all the population. Previous findings could only be considered as general if researchers took for granted that all the people perceived the stimuli similarly. As seen in this way, previous researchers have already attempted to show that people develop different kinds of perception of the light and colour according to age (Knez, 2001). Findings like these encouraged researchers to try to fill enormous gap in the field: do all brains react in the same way?

One of the most challenging and inspiring cases, from a point of view of an architect, is the case of people with autism. People with autism present several characteristics that impede them from perceiving the environment in the same way as individuals who are not diagnosed with autism. The different disorders and affections that affect people with autism, such as sensory processing disorder, even when considered apart from other differences found in the brain structure, suggest that the perception of these individuals is different, and that the current environment might not be suitable for them, maybe even being dangerous and detrimental for their behaviour and health. Therefore, being able to design proper buildings for them is the duty, and must be the priority, of architects and designers who could improve the quality of life of people with autism significantly by designing carefully bespoke spaces for them.

Even though many testimonies and much anecdotal evidence suggest that the light and colour, could have an important role in the lives of children with severe autism, the influence of colour and light on their mood has barely been examined, and no explicit work on this topic has been found.

The work presented in this thesis is the first study that examines how the colour or the source of the light (in this case, white, yellow, green, red and blue LED and fluorescent lights) might have the potential to change physiological signals and therefore, the mood of children with autism. To answer this question, an experiment was set up with the aim of understanding the different ways in which four individuals perceive the environment and its influence on their mood. In the first part of the investigation, the study considered whether the different lighting altered electrodermal arousal (EDA), the temperature of the tip of the nose and the rate per minute of repetitive behaviour. Secondly, a new method was proposed to translate these physiological signals into emotional states: the 3D Mood Box.

The influence of five colours of light and two sources of the light (LED and Fluorescent light) on the mood and physiology of children with ASD was tested under controlled conditions in a conditioned room in Prior's Court School. The participants were three young men and one young woman. The children were exposed to different lights in two 15-minute sessions per week, during seven weeks, and their physiological responses were measured and analysed. The four participants were monitored with skin conductance sensors, photographed with thermal cameras and recorded with video cameras when they played with their favourite toys under different light conditions.

The primary goal of the experiment was to show that it is possible to understand the way a child with autism responds to the colour and source of the light and how these impact on their mood. The experimental results showed that the responses are indeed highly idiosyncratic – that is, each participant had their own set of responses which were unique to them, and there is no suggestion that there was a set of responses that could be considered to be common to them all. For this reason, the amount of information per participant needed to be significant and the sample of participants had to be very limited.

No conventional statistical analysis was performed because, (1) each participant was taken to be an idiosyncratic individual, so that there was no 'group' comparison, (2) due to the particular individual characteristics of every participant, which meant that each participant needed special and dedicated attention, the variable values to be considered were very different for each participant and there was no basis for considering that any meaningful comparison could be made between participants. For example, the temperature of the tip of the nose is a common variable, but each participant had very different values and responses, which were particular to that participant and conveyed no meaning in comparison to any other participant. A conventional statistical analysis, which attempts to classify participants within a given class, could miss many of these differences, even though they surely influenced their behaviour. Instead, careful observation of the idiosyncratic characteristics of each participant, the variables involved, and the identification of variations in the physiological signals for that participant were more appropriate. Understanding each participant as a person in their own right was the priority, in order to understand better the relationship between the stimuli and their mood.

Accordingly, it was hypothesised that every participant could react differently and could be affected by the light differently. The analysis focused on the relative variations of the mood and body reactions instead on the significant variability. The analysis was done by observation and the results were represented visually for an intuitive evaluation.

The findings are discussed next.

8.1. Reinventing the method

8.1.1. 3D Mood Box: an experimental method

Overall, the experiments showed that, for each participant, the three physiological signals were consistent with each other most of the time. This indicates that the measurements were non-invasive measures that proved to identify the same features of the behaviour but in different ways. Therefore, it can be considered that EDA, the temperature of the tip of the nose and the RPM of tics are three physiological signals that are informative, non-invasive and complementary in relation to the identification of responses to given stimuli.

This 3D innovative approach served for many things but mainly to understand how the different features of the environment, in this case, the colour and the source of the light, could affect their mood, by using non-invasive tools that caused no trouble, that did not interfere in the performance and without the need of self-report questionnaires. Although this method is especially useful for those who cannot express such thoughts by themselves it might also be used with any individual and will help to get information about mood states without the need of relying on subjective methods, although further research would be required to establish the extent to which such an approach might be appropriate in specific cases.

The combination of the three physiological measures in this way provided rich information about the feelings and emotions of the participants.

This method also emphasises how differently people perceive things as every shape created with a group of metaballs obtained for each participant is different to the results from other participants.

These shapes also help to identify sessions that have been considered inconsistent because deviate from the norm. As the participants are very sensitive to changes in the routine, any alteration or uncommon event, can be reflected in their body responses, thus the 3D Mood Box can alert the researchers about it and researchers can investigate the possible events that could have impact on the results. For example, when searching for consistency in the daily analysis of the physiological and behavioural data, results of Participant F were not consistent on day 8, while they were consistent the rest of the days. These inconsistencies were also visible in the 3D Mood Box, as the metaballs of day 8 were always far from the consistent metaballs. However, results of Participant FX, for example, were consistent on day 8. This might indicate that the abnormal event that the researchers need to examine was a particular fact that affected Participant F but it did not affect the totality of the school. Another example was the inconsistencies found on day 10 across all the participants. This inconsistency across participants on one day in particular suggested that there was one particular event, unrelated to the experiment, which was relevant for all the participants, and affected their emotional responses.

Not only that, but this approach might also be helpful to understand the influence of many other factors. While the primary variables in this case study were the source and colour of the light, in principle, these variables could be changed to represent other features of the environment and then used to check their influence on people’s mood and body responses.

This method also has limitations. Although the selection of the two physiological responses (electrodermal activity and the temperature of the tip of the nose) and the repetitive behaviour analysis were useful for participants with autism, every kind of individual might require different signals to understand better their behaviour. For example, the rate per minute of tics would not be a suitable variable for people who do not suffer from tics disorders. Instead, in other cases, the third variable could be changed by other physiological signals such as heart rate or respiration rate.

This new approach is an innovative approach in an early stage that needs further work in order to be improved. For example, the meaning of the quadrants could be developed to have more accuracy.

To sum up, the method proposed served to inform the primary questions of this investigation which were whether the source (LED or fluorescent light) or the colour (Yellow, Green, Red, Blue) had an impact on the physiological signals and mood. In the affirmative case, the research showed that the light influenced every participant, how these influences were different in every case, and how these impacts found in the study can be compared with previous work performed with typically developed individuals by other researchers. After analysing the results and after answering these questions, many subquestions about the method and the results obtained came up and will also be discussed in this chapter.

8.1.2. Validation of the method by the occupational therapists of the participants:

The occupation therapists of each participant answered a questionnaire that served to compare the estimations of the child's mood obtained from the 3D Mood Box and the mood inferred by the therapists on the basis of their own criteria. The therapists received a video compilation with 30-second moments from the case study from each participant, and after each clip, they had to answer a few questions about the mood they thought that the participant displayed in the clip (to aid replicability, the questionnaire is given in Appendix J). In order to avoid some bias from the therapists, as some of the therapists might have a preconception of which colours might be better or worse for the mood of the participants, the videos were greyscaled. The estimation of the therapists was compared to the results obtained in the 3D Mood Box by participant and, at the end of each participant, the estimation was scored with a simple categorical scoring system to see how much therapists and 3D Mood Box agree.

To ease the evaluation and scoring: 'agreement between therapists and 3D Mood Box' = 3 points; 'partial but near agreement' = 2 points; 'partial but not near to agreement' = 1 point; 'disagreement' = 0 points. One of the points that this exercise has pointed out is that some of the physical (and thus observable) mannerisms could imply different moods, and that these might be differentiated better with physiological evidence, to which a therapist would not have normal access. Therefore, it is not a question of the mood box being 'wrong', but one of where it has access to more indicative information than the therapist. Therefore, to score 2 would mean where the physiological information is clear and adds to the therapist's interpretation enough to suggest that they would change their view; 1 would mean a non-agreement where the physiological information is less clear/strong, and if known by the therapist it would not change their view; a score of zero would be where the non-agreement is completely clear and unarguable.

The comparisons between therapists' responses and the results of the 3D Mood Box are explained by participants below:

- **Participant F**'s occupational therapist stated that the mood of the participant was the same as the ones that the 3D Mood box registered in five out of twelve clips. These times, it was the body language which helped the therapist to understand how the participant felt. The therapist and the 3D Mood Box identified relaxation and relief similarly from two clips, concentration from one clip, tiredness and sadness from another clip and distraction from another clip. In other words, both coincided in the identification of both negative and positive emotions.

  In four out of twelve cases, the therapist did not identify the mood of Participant F precisely the same as the 3D Mood Box did. However, the therapist managed to identify a few features of the behaviour of the participant that could correspond to the mood registered in the 3D Mood Box. For example, in one of the clips, the therapist considered that the participant felt "excited" because she was moving with the music. The 3D Mood Box registered that the participant felt "stressed and anxious". Two things that excitement and stress have in common are the elevated RPM of tics and the elevated arousal, and this was indeed the case in the data associated with this clip. However, as stated in Section 5.3 (Chapter Five), the temperature of the tip of the nose indicates whether the feeling is positive or negative, and the temperature of the nose during that particular clip was exceptionally low. If the temperature were higher (1 degree or 1.5 degrees), the results of the 3D Mood Box would have aligned with the criteria of the therapist. In this case, two things could have happened: (1) the temperature measurements were not correct or (2) the therapist might confound stress and excitement sometimes because the physical mannerisms are similar.

  A converse thing happened with another clip. The 3D Mood Box registered that the participant was feeling excited, while the therapist interpreted that the participant was feeling stressed due to the mannerisms. According to the therapist, the level of the voice of the participant was too low in volume to be excitement. Again, the temperature of the nose contradicted the therapist's interpretation.

In the other two clips in this category, the therapist identified the same positive/negative tendency of the emotional state of the 3D Mood box but did not interpret the same internal arousal of the participant. For example, in one clip, the therapist interpreted the participant's low levels of arousal as indicating stress, whereas the 3D Mood Box interpreted them as indicating that the participant was feeling 'sad and tired'. In the other clip, the therapist interpreted the participant as experiencing positive feelings, such as relaxation. However, the high level of arousal of the participant indicated that she was feeling positive feelings similar to happiness and amusement. In these two cases, the therapist's interpretation coincided with the 3D Mood Box insofar as saying that the feelings were positive or negative but did not identify the same description of the feeling. Internal responses such as arousal can sometimes be tricky to observe and tools such as skin conductance sensors can be more effective in determining the physiological response to changes such as arousal, that might not be so evident in physical mannerisms.

There were three out of twelve cases in which the 3D Mood Box registered that the participant felt negative feelings such as stress, tiredness or sadness but the therapist did not see them in the clips. In the first case, the therapist interpreted the participant as feeling a little tired and focused; however, the 3D Mood Box interpreted the participant as feeling stressed due to the high level of arousal. In the second case, the therapist interpreted the participant as feeling a little relaxed and focused; however, the 3D Mood Box interpreted the participant as feeling tired due to the low level of arousal and the low temperature of the nose. The difference between tiredness and relaxation in terms of physiological signals are the temperature of the tip of the nose and the RPM of tics. However, the physical manifestation of these two moods can appear very similar, for example, as a low level of activation. This could make it difficult for the therapist to choose which mood is being indicated by the physical mannerisms alone. In the third case, the therapist could not interpret a particular mood of the participant and stated that she might be a little bit relaxed, while the 3D Mood Box interpreted that the participant was feeling tired. Again, the temperature played an important role in identifying the positive or negative tendency of the participant.

To sum up, the occupational therapist of Participant F agreed most of the times with the criteria of the 3D Mood Box. Nevertheless, there were some discrepancies of criteria when considering the mood of the participant in terms of positive or negative valence (temperature of the tip of the nose) and arousal (high or low EDA). Table 8.1 shows the comparison between the 3D Mood Box and the responses of the therapist scored with the criteria explained at the beginning of the section. Results indicate that 3D Mood Box and the therapist would agree 72.2% of the times.

Participant F				
Clip	3D Mood Box interpretation	Therapist interpretation	Comment	Score
1	Relaxation and Relief	Relaxation and Relief	Same	3
2	Stress, Anger and Anxiety	Excited	The temperature difference	2
3	Concentration	Concentration	Same	3
4	Excited and Joy	Stressed	Temperature difference	2
5	Sadness, tiredness and frustration	Stressed	Temperature difference and mannerisms	2
6	Relaxation and Relief	Relaxation and Relief	Same	3
7	Sadness, tiredness and frustration	Sadness, tiredness and stress	Same	3
8	Stress, Anger and Anxiety	Concentration and a little bit of tiredness	Arousal and RPM tics	1
9	Distraction, tiredness and sadness	Relaxation and concentration	Temperature difference	0
10	Happiness and Amusement	Relaxation	Arousal difference	2
11	Distraction	No concentration and a little bit of anger	Same	3
12	Sadness, tiredness and frustration	Relaxed	Temperature & RPM tics	2
Total				26/36
%				72.2%

Table 8. 1. Comparisons between 3D Mood Box results and Therapist's interpretations. Participant F.

- **Participant FX**'s occupational therapist stated that the mood of the participant was the same as the 3D Mood box registered in seven out of fourteen clips. These times, it was the body language which helped the therapist to understand how the participant was feeling. The therapist and the 3D Mood Box identified relaxation and relief similarly from one clip, happiness and excitement from three clips, concentration and mental workload from another clip and pleasure from two clips.

In three out of fourteen cases, the therapist did not identify the mood of Participant FX precisely the same as the 3D Mood Box did. However, she managed to identify a few features of the behaviour of the participant that could correspond to the mood registered in the 3D Mood Box. For example, in two of the three clips, the therapist considered that the participant felt positive low arousing emotions such as relaxation and pleasure while the 3D Mood Box registered that the participant felt happy and amused due to the high level of arousal. The only difference between the feelings observed by the therapist (relaxation) and the feelings identified by the 3D Mood Box (happiness) is the level of arousal which cannot be observed from outside necessary. However, both the method and the therapist agreed that the feelings observed were positive. In the third clip, the therapist interpreted that the participant was focused and excited while the 3D Mood Box interpreted that the participant was focused and stressed. As mentioned above, two things that excitement and stress have in common are the elevated RPM of tics and the elevated arousal. However, the temperature of the tip of the nose indicates whether the feeling is positive or negative, and the temperature of the nose on that particular clip was low, indicating that the feeling tended to stress and not to excitement.

There were four out of twelve cases in which the 3D Mood Box registered that the participant felt negative low-arousing feelings such as annoyance, tiredness or sadness. However, the therapist did not see these emotions in the clips and only saw positive low arousing emotions such as relax and pleasure. The main difference between these feelings is the higher or lower temperature of the tip of the nose. It is crucial to bear in mind that the therapists watched the clips individually and responded to the questions independently from the rest of the videos. In other words, their responses correspond to a particular clip and not to the comparison between them, as the 3D Mood Box does to establish which light is better of specific purposes. If the results from these days were not based on the comparison of data from other days in which the participant was more relaxed and pleased, the results could be the same.

To sum up, the occupational therapist of Participant FX agreed most of the times with the criteria of the 3D Mood Box. Nevertheless, there were some discrepancies of criteria when considering the mood of the participant in terms of positive or negative valence that can be due to the lack of comparison between the clips. Table 8.2 shows the comparison between the 3D Mood Box and the responses of the therapist scored with the criteria explained at the beginning of the section. Results indicate that 3D Mood Box and the therapist would agree 81% of the times.

Participant FX				
Clip	3D Mood Box interpretation	Therapist interpretation	Comment	Score
1	Frustration, Tiredness and Sadness	Relaxation and Pleasure	Temperature difference	2
2	Pleasure and Interest	Relaxation and Pleasure	Same	3
3	Relaxation and Pleasure	Relaxation	Same	3
4	Happiness and Amusement	Relaxation, Pleasure and concentration	Arousal difference	2
5	Frustration, annoyance, sadness	Excitement and Relaxation	Temperature difference	2
6	Stress and Anger	Relaxed and Pleased	Arousal and temperature difference	1
7	Excitement and Joy	Excitement and Pleasure	Same	3
8	Concentration	Concentration and Pleasure	Same	3
9	Happiness and Amusement	Relaxation and Pleasure	Arousal difference	2
10	Excitement and Joy	Excitement and Pleasure	Same	3
11	Relax and Relief	Relax and Relief	Same	3
12	Frustration, Tiredness and Sadness	Relaxation	Temperature difference	2
13	Concentration and Stress	Relaxation and Excitement	Temperature difference	2
14	Happiness	Happiness	Same	3
Total				34/42
%				81%

Table 8. 2. Comparisons between 3D Mood Box results and Therapist's interpretations. Participant FX.

- In the case of **Participant H**, the opportunity arose for two therapists to observe the clips, so it was also possible to compare their views to each other as well as to the 3D Mood Box. The two therapists did not agree with each other some of the times. However, both therapists stated that the mood of the participant was the same that the 3D Mood box registered in the same four out of nine clips, the last four clips. These times, it was the body language which helped the therapist to understand how the participant was feeling. The therapist and the 3D Mood Box identified relaxation and relief similarly from two clips, and concentration and mental workload from other two clips.

There were cases when the therapists did not identify the mood of Participant H precisely the same as the 3D Mood Box did. However, they managed to identify a few features of the behaviour of the participant that could correspond to the mood registered in the 3D Mood Box. For example, in the first clip, one of the therapists considered that the participant felt a little bit relaxed but also stressed; the other therapist stated that the participant was a little bit sad, tired and stressed. The 3D Mood Box, on the contrary, registered that the participant was relaxed and relieved. As stated in Section 6.5 (Chapter Six), two things that tiredness and relaxation have in common are the low level of arousal. However, the temperature of the tip of the nose indicates whether the feeling is positive or negative, and the temperature of the nose on that particular clip was higher than usual, hence the mood box result (and of course the therapists could not observe this phenomenon).

For this reason, the 3D Mood box established that the predominant feeling of the participant was relaxation. Both therapists agreed on the level of the arousal of the participant according to the feelings that they selected in the questionnaire. However, the therapists disagreed with each other and they each identified the opposite valence. One of the therapists also stated that the participant felt contradictive feelings such as stress and relax.

In the second clip, both therapists agreed that the participant felt focused because the participant was engaging with the activity. However, the 3D Mood Box also registered that the participant was excited as a result of increased EDA and high RPM of tics. The therapists did not mention happiness or excitement. The concentration of the participant might have masked the excitement that the activity could provoke him.

In the third clip, one of the therapists stated that the participant was tired; the second therapists stated that the child was feeling upset and not very concentrated on the task. The 3D Mood Box registered that the participant was distracted. Although the therapists suggested that the mood of the participant was different from the one that the 3D Mood Box registered, the therapists agreed with the 3D Mood Box that the feeling that the participant was feeling was low arousing and negative.

In the fourth and fifth clip, both therapists agreed that the participant was feeling relaxed and focused; the 3D Mood Box registered that the participant was excited. Although both feelings are very different, both feelings are positive, so the therapists and the 3D Mood Box agreed that the participant was feeling good. However, the high levels of arousal were masked by the lack of smiles and expressive behaviour observed in the clip.

To sum up, the occupational therapists of Participant H agreed many times with the criteria of the 3D Mood Box. Nevertheless, there were some discrepancies of criteria when considering the mood of the participant in terms of arousal or positive or negative valence. Table 8.3 and Table 8.4 show the comparison between the 3D Mood Box and the responses of the two therapists scored with the criteria explained at the beginning of the section. These two tables also show that the interpretation of the therapists are not always the same (see clips 1, 2, 3 and 7). Results indicate that 3D Mood Box and the therapists would agree 70.4% and 74% of the times, respectively.

Participant H				
Clip	3D Mood Box interpretation	Therapist 1 interpretation	Comment	Score
1	Relaxation and Relief	Relaxation and Stress	Temperature difference	2
2	Happiness and Excitement	Concentration	Temperature and RPM tics difference	1
3	Distraction	Tiredness	RPM tics	2
4	Excitement and Joy	Relaxation	Temperature difference	2
5	Happiness and Excitement	Relaxation	Temperature difference	2
6	Concentration	Concentration and pleased	Same	3
7	Concentration	Positive feelings	Not enough information	1
8	Relaxation and Pleasure	Relaxation	Same	3
9	Relaxation and Relief	Relaxation	Same	3
Total				19/27
%				70.4%

Table 8. 3. Comparisons between 3D Mood Box results and Therapist's interpretations. Participant H.

Participant H				
Clip	3D Mood Box interpretation	Therapist 2 interpretation	Comment	Score
1	Relaxation and Relief	Stress, Anger, Sadness and Tiredness	Arousal, RPM tics and temperature difference	0
2	Happiness and Excitement	Relaxation and Concentration	Arousal difference	2
3	Distraction	Relaxation and upset	Temperature difference	2
4	Excitement and Joy	Relaxation and Concentration	Arousal difference	2
5	Happiness and Excitement	Relaxation	Arousal difference	2
6	Concentration	Concentration and Pleasure	Same	3
7	Concentration	Concentration	Same	3
8	Relaxation and Pleasure	Relaxation and Pleasure	Same	3
9	Relaxation and Relief	Relaxation and Pleasure	Same	3
Total				20/27
%				74%

Table 8. 4. Comparisons between 3D Mood Box results and Therapist's interpretations. Participant H.

- **Participant J**'s occupational therapist stated that the mood of the participant was very similar to the 3D Mood box registered in seven out of eighteen clips. These times, it was the body language which helped the therapist to understand how the participant was feeling. The therapist and the 3D Mood Box identified relaxation and relief similarly from one clip, pleasure from three clips, excitement from one clip, tiredness and sadness from another clip and distraction from another clip. In other words, both coincided in the identification of both negative and positive emotions.

  In three out of eighteen cases, the therapist did not identify the mood of Participant J precisely the same as the 3D Mood Box did. However, the therapist managed to identify a few features of the behaviour of the participant that could correspond to the mood registered in the 3D Mood Box. For example, in one of the clips, the therapist considered that the participant felt relaxed; the 3D Mood Box registered that the participant felt distracted. Two things that relaxation and distraction have in common are the low level of RPM of tics and the low level of arousal. However, the temperature of the tip of the nose indicates whether the feeling is positive or negative, and the temperature of the nose on that particular clip was lower than usual, indicating that the participant might be feeling distracted. A similar thing happened with another clip. The 3D Mood Box registered that the participant was feeling happiness and contentment, while the therapist interpreted that the participant was feeling focused. Both feelings share the low RPM of tics and the high level of arousal but, again, the high temperature of the nose contradicted the therapist's interpretation.

In another clip, the 3D Mood Box registered that the participant was feeling stress and focused, while the therapist interpreted that the participant was feeling focused. Both method and therapists agreed with the mental workload, but the therapist did not observe stress.

There were seven out of eighteen cases in which the 3D Mood Box registered that the participant felt negative feelings such as stress, tiredness or sadness but the therapist did not see them in the clips and saw positive feelings such as relaxation, pleasure and excitement, instead. In these cases, even though the level of arousal and the RPM of tics might be similar between the method and the criteria of the therapists, the temperature of the tip of the nose gave nuances about the feeling the participant was feeling.

To sum up, the occupational therapist of Participant J agreed with the 3D Mood Box some of the times with the criteria of the 3D Mood Box. Nevertheless, there were some discrepancies of criteria when considering the mood of the participant in terms of positive valence. Even though the observations were similar (High/low arousal or high/low RPM of tics), the temperature of the tip of the nose indicates that the tendency of the feelings was the opposite. Table 8.5 shows the comparison between the 3D Mood Box and the responses of the therapist scored with the criteria explained at the beginning of the section. Results indicate that 3D Mood Box and the therapist would agree 74% of the times.

Participant J				
Clip	3D Mood Box interpretation	Therapist 1 interpretation	Comment	Score
1	Pleasure and Interest	Pleasure and Relaxation	Same	3
2	Distraction	Relaxation	Temperature difference	2
3	Frustration, Tiredness, Sadness	Concentration, Relaxation and Pleasure	Temperature difference	2
4	Distraction	Distracted	Same	3
5	Stress and Anxiety	Relaxed and Pleased	Arousal and temperature difference	0
6	Happiness	Concentration	Temperature difference	1
7	Sadness and Annoyance	Concentration and pleased	Temperature difference	2
8	Excitement and Joy	Excitement and pleasure	Same	3
9	Relaxation	Relaxation	Same	3
10	Stress and Anxiety	Excited, Pleased and Tiredness	Temperature difference	2
11	Stress	Excitement and relaxation	Temperature difference	2
12	Frustration, Tiredness, Sadness	Tiredness	Same	3
13	Stress and Concentration	Concentration		2
14	Tiredness, Sadness	Relaxation and Tiredness	Temperature difference	2
15	Relaxation and Relief	Concentration and Tiredness	Temperature difference	2
16	Relaxation and Pleasure	Relaxation and Pleasure	Same	3
17	Relaxation and Pleasure	Relaxation and Pleasure	Same	3
18	Relaxation and Relief	Concentration	Temperature	2
Total				40/54
%				74%

Table 8. 5. Comparisons between 3D Mood Box results and Therapist's interpretations. Participant J.

As the therapists based their responses on the participant's body language and their particular mannerisms and the amount of them, they might have difficulties in detecting the levels of activation that the participant had. Sometimes the participant shows higher levels of arousal, and because they are not doing something in particular, the therapists believe they are relaxed and calmed.

Nevertheless, when the levels of activation are correctly observed, the positive or negative valence is not always the same when comparing the responses from the therapists and the 3D

Mood Box. In these cases, the temperature of the tip of the nose can help to determine whether the feelings are positive or negative. However, it is essential to remember that the therapists answered questions about particular and individual clips. The 3D Mood Box, instead, uses all the data obtained from each participant and compares the results from different light conditions to evaluate which light can be more suitable than others to satisfy specific purposes. That is why might therapists interpret that, for example, the participant feels relaxed and the 3D Mood Box interprets that the participant is distracted: it could be due to the relative location of the data points on the box and not because the answers or the results from the method are mistaken. Besides, therapists might be used to observing very upsetting tantrums or very extreme situations that they relate to stressful situations, and these events might not have happened during the sessions, or the clip observed.

It is also worth pointing out that the therapists were only able to observe physical activity, not the physiological data that the 3D Mood Box is using. If the therapists saw more clips they would not be able to make any different interpretation of the clips already evaluated, but if they could access to the physiological data of the 3D Mood Box, the therapists might change some of their responses.

Another issue to take into consideration is that the therapists observed a short clip extracted from five-minute light exposure. While each data point introduced in the 3D Mood Box correspond to the average of all the data obtained during the light exposure, the therapists only saw a small portion of them so that the interpretations might differ.

Apart from these notes, the 3D Mood Box, as explained in Chapter Six, indicates the tendency of the feeling of the participant. It does not mean that the participant might feel many different emotions during the session. These nuances can be identified by careful observation from the therapists.

8.2. Impact of LED light vs Fluorescent light:

Many testimonies around the globe, and also therapists from the school where the tests took place, stated that the Fluorescent light might be detrimental for children with autism and children with sensory processing disorders because of the flicker and buzz that came from the light. It is considered that Fluorescent light can provoke migraine and tantrums on children who can perceive these changes in the light every day, elevating their anxiety levels and worsen their quality of life and well-being.

As far as can be ascertained, no previous scientific work has been done specifically about the influence of the fluorescent light on the mood of children with autism even though fluorescent light is the most-used lighting system in public spaces and work spaces nowadays. Many guidelines suggest that would be more beneficial to children with autism than Fluorescent light, even though it has been proved that some also may flicker if the power supply is not constant. However, the flicker of the Fluorescent light is more aggressive as it has a flicker rate of 120Hz, compared to the 50-60hz (depending on the power supply and the country) that the LED might have. Flicker is generally perceived by humans at frequencies slower than 50 Hz. However, people with sensory processing disorder such as children with autism can notice much higher frequencies, perceiving indirectly stroboscopic effect and seeing the environment in images and not as movement.

In order to see if LED was more suitable than Fluorescent light, two white light conditions were studied in the therapy room: White and (White) Fluorescent light. Both had similar colour temperature and intensity so apparently, there were no differences that could indicate that there were two different lights which were set in the room, except the high-speed flicker and the buzz that were supposed to come from the fluorescent lights.

While the Colour Temperature of White was 6535K, the Colour Temperature of Fluorescent light was 6400K. Therefore, the CT of White was slightly higher than the CT of Fluorescent light. In other words, White was composed of more particles of blue than Fluorescent Light, although the difference is so small that it might be imperceptible. Moreover, the average illuminance on the table due to the three white LED bulbs was 46.2 lux, while the three fluorescent bulbs provided with an average illuminance on the table of 45lux. Again, even though the measurement were not precisely the same, they were for all purposes identical (the human eye cannot perceive such small differences in illuminance at this light level).

Unfortunately, it was not possible to replicate in the room where the experiments took place the same lighting system that Prior’s Court has in its educational facilities because a more sophisticated and powerful LED system was necessary to do so. Therefore, it was not possible to replicate the vibrant intensity, a characteristic of the lighting system implemented in the school that can also be one of the reasons the children do not cope well with the lights. For this reason, the influence of the lighting system the children are exposed every day was not tested in comparison to other sources such as LED with similar properties.

Instead, fluorescent bulbs were added to the designed lighting system in the experiment room, and White replicated as much as possible the properties of the Fluorescent light. Proceeding like this, it was possible to study whether the possible presence of the flicker and the buzz of the fluorescent light could have a detrimental impact on the participants, and observe if LED lights were more suitable than the fluorescent light sources.

According to Knez et al. (2001) and Kuijsters et al. (2015), older people perceive the light differently from young people. Their work suggests that the results found in this experiment might be different from previous work about the influence of the light because it deals with children that, above all, have severe autism. These characteristics from the participants who participated in the experiment might influence the results as well.

8.2.1. Does the source of the light impact on the physiological signals and behaviour?

Even though some similarities were found across participants, results show that the influence of the different sources of the light on the physiological signals is not the same across the participants.

In terms of EDA, Fluorescent light seemed to be more arousing than White for most of the participants. This finding might suggest that the theories of the therapists and other testimonies were correct and that the Fluorescent light had an arousing effect on the students, most likely due to the flicker and buzz of the light. All participants were more aroused under Fluorescent light than White except Participant FX. Results from Participant F, H and J, seem to be in line with the work of Baumeister & Forehand (1974) and the testimonies of Temple Grandin (1996) and Andrew Brand (Brand, 2010).

However, results of the temperature of the tip of the nose and the RPM of tics under Fluorescent light show that this source of light did not necessarily influence the participants negatively compared to White as expected. According to Ioannou, Gallese & Merla, (2014) and Panasiti et al. (2016), a reduction in temperature at the nose can be linked to an increase in fear and stress. Nevertheless, only participant H showed lower measurements of temperature in the nasal area under Fluorescent light than under White LED. Participants F and J showed similar temperature measurements under White and Fluorescent light, indicating that the different influence that both lights can have in their mood is not significantly negative. Participant FX had higher temperature measurements on the tip of the nose under Fluorescent light, indicating that, in his case, the Fluorescent light might evoke more positive feelings, such as relaxation, than White light.

Regarding the rate per minute of tics, Participants F and H had more tics under Fluorescent light, but Participants FX and J had more tics under White LED lights. As mentioned in Chapter Five, it is known that repetitive behaviour is aggravated by anxiety and stress, or excitement; and reduced during sleep, doing high concentration tasks, being distracted and in emotionally pleased situations (Harris & Singer, 2006). Just paying attention to the RPM of tics obtained, and considering that reducing tics is one of the primary purposes of environmental therapy, Participants F and H showed that White might be more beneficial to them than Fluorescent light. However, Participants FX and J showed opposite results. According to Colman et al. (1976), the RPM of repetitive behaviour tends to increase under Fluorescent light conditions. Results from this experiment show that only 50% of the sample showed results that match this expectation. However, it would be necessary to replicate the properties of the light from Colman experiments to see if, in these situations, the results are more similar or not. Nevertheless, it is interesting that the outcome for these lights is at least equivocal.

Overall, these results indicate that there is, in fact, a difference in perception of these two sources of light and that these two sources impact the physiological signals differently, even though both lights have almost same colour temperature and illuminance; but the influence might be different for each participant.

Taking the combination of physiological signals together, results show that:

- Participant F had higher levels of tonic arousal under Fluorescent light, similar temperature under White and Fluorescent light conditions, and more RPM of tics under Fluorescent light. Therefore, it can be said that due to this combination of factors, White might be more beneficial for Participant F than Fluorescent light. Therefore, data obtained from Participant F indicates that the hypotheses about the influence of the Fluorescent light might be correct.
- Participant FX had lower levels of tonic arousal under Fluorescent light, higher temperature under Fluorescent light than under White conditions, and less RPM of tics under Fluorescent light. Therefore, it can be said that due to this combination of factors, Fluorescent light might be more beneficial for Participant FX than White. Therefore, data obtained from Participant FX contradict the anecdotal evidence.
- Participant H had higher levels of tonic arousal under Fluorescent light, lower temperature under Fluorescent light than under White conditions, and more RPM of tics under Fluorescent light. Therefore, it can be said that due to this combination of factors, White might be more beneficial for Participant H than Fluorescent light, and all

the physiological signals support this statement. Therefore, data obtained from Participant H indicates that the hypotheses might be correct.

- Participant J had higher levels of tonic arousal under Fluorescent light, similar temperature under White and Fluorescent light conditions, and less RPM of tics under Fluorescent light. Therefore, it can be said that due to this combination of factors, Fluorescent light is neither detrimental nor beneficial for Participant J than White. Therefore, data obtained from Participant J neither contradict nor support the anecdotal evidence. While in some situations it might be necessary that the participant is less aroused and White might be more suitable, the fact that the participant had less RPM of tics under Fluorescent light is also something to take into consideration. Results from the different body responses suggest that Fluorescent light might enhance more concentration than White.

To sum up, two out of four participants showed that White might be more beneficial than Fluorescent light, one out of four participants showed that Fluorescent light might be more beneficial than White, and one out of four participants showed that one light could be more suitable for specific situations and the other would be more suitable for others.

Nevertheless, as mentioned in Chapter Seven, positive emotional responses under Fluorescent were unexpected. The translucent shade and the low intensity of the fluorescent system might have caused a reduction of the flicker, thus impacting on the results. For this reason, further research with the fluorescent lighting system already installed in the academic facilities could be helpful to determine the real effects of the fluorescent source.

These findings suggest that the participants who were more aroused and had more tics (Participant F and Participant H) might have felt the possible flicker and the buzz that came from the Fluorescent light. Nevertheless, it is also believed that brightness can also be a detrimental factor for children with autism. Even though the properties of both lights were intended to be as similar as possible, White was slightly more bright than Fluorescent light (White 6535K and Fluorescent light 6400K). This factor might be the one which triggered these results in Participant FX and Participant J, indicating that, while the first two participants mentioned might be more sensitive to the flicker and the buzz, the other two participants might be more sensitive to brightness. It is also possible that the diffusers used in the experiment room could have masked the flicker, by delaying the fade of the light during the time when it had flicked to off, and this might have affected these outcomes. However, the fact that two of the participants did react to the fluorescent light in the expected way suggests that the effect was present, so perhaps the other participants were less sensitive to this particular feature.

These findings are preliminary, and a longer experiment is necessary to confirm these findings. It would be useful, as well, to test the influence of the current fluorescent lighting system in the school that the participants experience every day as the therapists indicated during the interviews, prior the case study, that the fluorescent light of the school might increase migraine and stress in the students. The current system comprised fluorescent tubes, without diffusers, and provided brighter light than the one used in the experiments.

8.2.2. Does the source of the light impact on their mood?

The changes mentioned in the body responses suggest that the source of the light might induce different feelings in the participants. Results from the 3D Mood Box analysis (Chapter Seven) also reveal that although in some cases a participant revealed a consistent impact on their mood in relation to the source of the light, the findings in this experiment indicate that the source of the light could induce inconsistent feelings in the participants. Even though some similarities in mood can be observed, the source of the light influences each participant differently, thus emphasising the idea that the environment and the features of the built environment are perceived differently by every person.

This was shown by the metaball analysis. The metaballs did not coalesce with a multiplier factor of 1.5 in most of the cases, meaning that both lights seemed to cover many possible feelings. This indicates that the mood under these two sources of light cannot be predicted, so the light source cannot be used to achieve particular purposes. This result is consistent with Gerard's (1958) work: when studying the impact of the colour white, he found that responses under White light varied substantially and that no consistent findings were observed.

In terms of valence, on the one hand, White seemed to induce positive feelings in Participants F and H, and negative feelings in Participant J. Participant FX, however, seemed to be neutral in relation to valence.

On the other hand, Fluorescent light seemed to induce positive feelings in Participant F, FX and Participant J. Participant H, however, felt negative feelings (even though the sample of Participant H was exceptionally small so these results should be treated with due caution).

Thus, most of the participants felt positive feelings under both sources of light compared to all the types of lights studied and introduced in the 3D Mood Box, indicating that none of them has a demonstrated detrimental impact on their mood compared with the other.

However, if therapists were to choose which one of them to use before the other, it would be required to focus on the physiological signals mentioned and on the purpose of the light and the participant: if it is necessary that the participants are more relaxed, the therapist would need low arousing ambiences and ambiences that reduce the rate per minute of tics; if there is any activity that requires high concentration, high arousing ambiences would be necessary; in bed-rooms it would be more suitable to have low arousing ambiences to facilitate the sleep process, among others.

It is vital to remember that the Fluorescent light conditions studied in this case study were not the same than the ones that are installed in the school so these results cannot be generalised nor served as an indicator that White and Fluorescent light have, in all the circumstances, a similar effect. Additional research about the topic would be required to check if the effect of the flicker and the buzz of higher intensity fluorescents without diffusers are more noticeable and if the light has similar effects in health and well-being for the participants.

8.3. Impact of the colour of the light:

The LED colours tested were Yellow, Green, Red, and Blue. Their properties are explained in Chapter Three. Based on previous work (Wilms & Oberfeld, 2016) the four colours were balanced in saturation and intensity but varied in hue (wavelength). This means that any change in physiological signals might be due to the hue and wavelength of the coloured light. Although illuminance was not a property taken into consideration in previous work, illuminance measures were taken in this case study, showing different illuminance for every coloured light conditions on the table surface where all the activities took place. In other words, the feeling of clarity might be different, and this factor might also influence the results. The primary purpose was to equalise all the properties as much as possible, but in order to balance the illuminance between all the colours, the other properties were impaired. Finally, it was decided that it was more important to maintain saturation and intensity at the same levels than illuminance. Despite that, it is essential to bear in mind the illuminance differences in the discussion.

Results show that the colour of the light does influence the three physiological signals of the participants. Even though some similarities were found, the influence of the different colours of the light on the body responses and, consequently, their mood which results from the combination of the three signals, is not the same across the participants most of the times.

8.3.1. Does the colour of the light impact on the physiological signals and behaviour?

Findings from EDA, temperature of the tip of the nose and RPM of tics all suggest that the colour of the light could have an impact on all of the participants. Many times, the results obtained for each colour of the light seemed consistent within the different sessions of each participant, and a few times, also across participants.

Interestingly, the analysis of the skin conductance across the days showed, sometimes, patterns during the session. Participants F and FX's trend-line of the arousal was in most cases upward over the day, although EDA in Participants H and F did not present a pattern.

The increasing trend-line observed in Participant F and FX might be a response to three possible causes. First, the increasing arousal could respond to a sweat accumulation on the sensors over time. If this occurs, the accumulation of sweat provides the same signal as a high arousal response, although if it was the case, it would be expected to the other participants, as well. Secondly, results could indicate that the participant might have felt more stressed over the sessions, regardless of the colour of the light. This premise seems unlikely because, according to the therapists, the participants might tend to be more stressed at the beginning of every activity due to its uncertainty. However, higher arousal might indicate as well either excitement or a mental workload. These results might also indicate that the participant increased their excitement or concentration respectively over the time in the session. Third, the participants could be influenced by the colour of the light, and the upward trend-line of the arousal is due to the colour of the light. Results observed in many sessions would support the third premise because the results of the same light on different days were consistent no matter the order and location of the light. Other results, though, might support the premise that the participant felt more concentrated or excited throughout the session, regardless of the colour (but take note of the therapists' comments reported above).

Despite that, decontextualising all the measures of EDA obtained under different colours, the average of all the measures obtained suggests that there is a strong impact of the colour in the skin conductance. In terms of EDA, Blue seemed to be lowest arousing colour for two out of four participants (Participant F and H), although Blue was low arousing for Participant J, as well. According to Fehrman & Fehrman (2004) and Cajochen (2007), from a biological point of view, blue light, as a short-wavelength colour, is supposed to be an arousing and alerting light, compared to other colours with longer wavelength; thus it was expected that blue might have an arousing effect. Nevertheless, results for three out of four participants contradict this finding.

However, in the broader context, the psychological associations of the participants might be crucial (Goldstein, 1942). The participants who presented lower arousal under Blue might link the colour blue to something that makes them feel relaxed, and this association could have had an essential influence on the results. Our participants, in particular, might have associated the colour blue to safety as all the uniforms of the students, and the therapists and carers are blue.

Nevertheless, Participant FX was more aroused under Blue than under any other coloured light condition. Results of Participant FX might suggest that the biological influence of the light might prevail or that the associations linked to the colour are different from the rest of the participants. Unfortunately, it is very challenging to identify the associations that children create to familiar objects and colours, as they are not necessarily the same as cultural and historical links that are present in society.

Participant F showed that Yellow was the most arousing colour, then Red followed closely by Green and Blue the least arousing colour. This finding indicates that the more arousing colours for Participant F are the long-wavelength colours, and the less arousing are the short-wavelength colours. This finding coincides with the most of previous work such as Goldstein (1942), Gerard (1958), Wilson (1966), Jacobs and Hustmeyer (1974) and Wilms et al. (2016), among others, although some of them consider that Red is more arousing than Yellow. This finding might respond to an indirect influence from a psychological level, although the associations of colours might not be the same. According to Goldstein, red and yellow might undermine performance when a task requires concentration, while blue and green might enhance the concentration. However, further research in evaluating performance is necessary to confirm how these colours influence performance and concentration in these children.

Participant J showed as well that Yellow was the most arousing colour, but the levels of arousal were pretty similar under Green, Blue and Red. After Yellow, Green was the more arousing colour followed closely by Blue and Red, the least arousing colour. This finding indicates that Participant J is aroused by the colours independently of the wavelength of the colour and light. This finding might respond to an indirect influence from a psychological level, although the associations of colours might not be the same as the other participants.

Participant FX and Participant H showed similar variations of skin conductance under all the colours except for Blue. For Participant H, Green is the most arousing colour, then Red followed closely by Yellow, and finally Blue. In the case of FX, Green is the most arousing colour, followed by Blue, followed by Red and Yellow. In the case of Participant H, as mentioned before, Blue was the least arousing colour. Despite the similarities in EDA under Yellow, Green and Red, this finding shows two different kinds of perception of the colour of the light in the two participants.

On the one hand, Participant FX is more aroused by the short-wavelength colours, and less aroused by the long-wavelength colours. This finding contradicts the literature which focuses on the influence of the colour from a psychological level, such as Goldstein (1942), Gerard (1958), Wilson (1966), Jacobs and Hustmeyer (1974) and Wilms et al. (2016), among others; but coincides with the colour influence from a biological point of view, in which short-wavelength colours (green and blue) are more arousing than long-wavelength colours (yellow and red) (Fehrman & Fehrman, 2004; Kaiser, 1984; Thapan et al., 2001; Warman et al., 2003; Wright, 1998). This finding indicates that the colours could impact on the skin conductance of Participant FX directly at a more instinctive and biological level.

On the other hand, Participant H, like Participant J, is aroused by the colours independently of the wavelength of the colour and light. While, as mentioned before, Blue is the least arousing colour for Participant H, the most arousing colour is Green, and these are both short-wavelength colours. In between these colours, in terms of arousal, we can find Red and Yellow which shows similar level of arousal with slightly but not significantly higher arousal under Red. This finding partially contradicts the literature. While low levels of arousal under Blue might support the previous work based on the psychological associations to Blue (Gerard, 1958; Goldstein, 1942; K. W. Jacobs & Hurstmyer, 1974; Wilms & Oberfeld, 2016; Wilson, 1966), high levels of arousal under Green might indicate two possible reasons. Either Participant H has linked the colour Green to different and unpredictable associations or the participant is biologically and directly aroused. Either way, the sample of Participant H is minimal and further research would be necessary to respond to these questions and see if the results are consistent.

Even though some results of the electrodermal activity might be similar between some participants, it does not mean that these results mean the same. As previously seen, increase in arousal can indicate different outcomes sometimes (Blechert et al., 2006; Christie & Friedman, 2004; Demaree et al., 2004; Murakami & Ohira, 2007; Ritz et al., 2005), as does decrease in arousal. These nuances can also be intuited by the variations of the Phasic EDA (number of peaks). Tonic and phasic arousal signals are not always consistent with each other. That means that the different colour of the light could impact differently in the different levels of arousal and types of stress. For example, in some cases, a specific colour of the light can be arousing in long-term situations (tonic EDA) while the instant responses might be low (phasic EDA), or vice versa. Other times, the participants might experience different levels of phasic arousal, presenting inconsistent number of peaks, but it can also be caused by different and unusual external stimuli, not constant throughout the sessions (for example, hearing children screaming in the corridors). This is why crossing the body responses can reflect truly how the different types of light influence the participants and if these similarities remain similar in all the signals.

Similarly, as seen in the EDA responses, the daily analysis showed that the temperature of the tip of the nose in the case of three out of the four participants had an upward trend-line in between 50-75% of the sessions. This increase can indicate two possible reasons. First, the participant might be getting used to the session, and the increase in temperature could indicate that the participant was feeling more comfortable with the situation, no matter the colour of the light. In the affirmative case, the increased trend-line for the temperature of the tip of the nose would coincide with results found in tonic EDA. Second, they could be influenced by the colour of the light which was set at the end of the session, indicating that the last colour of the sequence is the more arousing colour. The second premise would be contradicted by results observed in participant F for Red and White s, which are lower when they were located at the beginning or in the middle of the session. Unfortunately, there are not enough examples to clarify whether the first premise or the second is correct. Participant J wanted to change the colour of the light often. Half of the days, he experienced more than three lights – in some cases, lights were even repeated. Due to these anomalies in the experiment, more fluctuations in physiological signals were observed. For example, on the days in which this participant experienced more than three different lights, his physiological measures showed neither a clear upward trend-line nor a downward trend-line, nor did it show more consistent fluctuations as was expected at the beginning of the experiment. For example, participant J, on day 3, had few exposures to Blue was set, and one of them was in between two Yellow exposures. The temperature of the tip of the nose was higher under Blue light than under Yellow light exposures. These results were consistent and showed lower temperatures under yellow than under Blue across that day. In other words, participant J recovered the same temperature of the nose under the Yellow after experiencing other light conditions which also changed their temperature of the tip of the nose.

Despite that, decontextualizing all the measures of the temperature of the tip of the nose obtained under the different colours, the average of all the measures obtained suggests that there are many similarities between Participant F, Participant H and Participant J, similarly to results found for EDA, which also showed similarities between these three participants.

The similarities found between these three participants were, firstly, Green seemed to induce a higher temperature at the tip of the nose. This finding indicates that Green might induce positive feelings in the participants. Second, measurements under Yellow and Blue were similar to each other and slightly lower than under Green. Finally, these three participants also showed that their lowest temperature measurements were collected under Red , indicating that Red might induce negative feelings (Ioannou et al., 2014; Panasiti et al., 2016). Unexpectedly, all the variations of the temperature of the tip of the nose under coloured light conditions were similar between these three participants.

To sum up, the colour that might induce more positive feelings, according to the temperature of the tip of the nose of these three children is Green, followed by Yellow and Blue, and finally, Red. Red seems to be the colour which induces the more negative feelings. These findings support the literature regarding negative influence in mood due to the colour red, such as the work of Kwallek et al. (1996) which reported more unpleasantness during Red light exposures in office environments, and the work of Elliot et al. (2007) who associated the colour red to negative feelings such as danger and failure in the academic environment. While Red is psychologically associated with negative feelings, green is associated with relaxing and nature. This finding, though, also emphasises the idea that the property which influences the temperature of the nose is the hue, but not necessarily the wavelength.

These preliminary results could suggest that they could be extrapolated and generalised and that the colour of the light might influence the temperature of the tip of the nose equally in children with autism. However, it is necessary to be cautious about this as one of the four participants showed a different reaction to the colours and the sample of participants and the sample of session for each participant is very small. What this does show though is that different children with autism may have different responses, but that they are individually consistent about these: the important learning point from this is that it is necessary to discover the particular set of responses for each child.

Results from the temperature of the nose of Participant FX under different coloured light conditions show that the temperature of the tip of the nose is higher under Yellow, followed by Blue and Red, and finally the lowest temperature of the tip of the nose is observed under Green. In other words, Yellow might be the colour which enhances more positive feelings and Green might be the colour which induces less pleasant and more negative feelings among all the colours studied. This finding is contrary to the findings observed in the other participants.

An interesting fact is that, even though more differences between the participants were expected, three out of four participants (Participant F, Participant H and Participant J) showed similar results (with nuances) between each other regarding EDA and nasal temperature. This finding indicates that the different colours of the light studied might affect these two physiological signals similarly and consistently. There is only one participant, Participant FX, who showed not only different but sometimes, contradictory results. The phenotypes of the participants can be very helpful when trying to identify the causes that provoke these differences. Although all the participants have been diagnosed with sensory processing disorder, the diagnosis file of Participant FX was particularly different and stated that Participant FX has “profoundly atypical sensory processing difficulties”. The “profound” and “atypical” way of perceiving the environment, compared to the other participants, could be one of the reasons, if not the reason why, this participant present as many differences as he does.

These findings indicate that, even though some similarities can be found between children with autism that would make us believe that the influence of the environment can be generalizable, there will always be part of the collective who will deviate from the norm and will give sense to the idea of having bespoke solutions.

Sensory processing disorders might affect every person differently, and it is important to bear all these differences in mind. As Delacato (1974) and Mostafa (2007, 2014) suggested, segregating the children depending on their sensory needs might be more sensible than segregating them chronologically or based on their cognitive age.

It was during the analysis of the repetitive behaviour where the differences between the individuals manifested more strongly.

Regarding the rate per minute of tics, there were no similar results between participants. While Participant F experienced a higher RPM of tics under Red , Participant FX experienced more tics under Blue , Participant H had more tics under Yellow and Participant J had more tics under Green conditions. Considering that an increase in RPM of tics is a consequence mainly of anxiety or stress (although sometimes it can mean excitement, as well), this finding suggests that the conditions that provoke stress in one child are not necessarily the same for another. In other words, the colour of the light does influence the participants, but it has a different influence in each case.

The fact that the nasal temperature during these colours for Participants F, FX and H were lower than other colours suggests that these are colours which should be avoided in order to decrease the RPM of repetitive behaviour and negative and unpleasant feelings. Nevertheless, results from Participant J, who experienced a more considerable amount of tics but also higher nasal temperatures under Green , indicate that the elevated RPM of tics that Participant J suffered was not due to anxiety and stress but to happiness. These results confirm our suspicions, as the participant tended to speak on his own in a happy mood, under Green .

To sum up, the different impact that the colour of the light had in the different body responses indicates that the colour of the light might have an impact on the physiological signals of the participants, and therefore, on the mood. These findings are considered as preliminary findings, and further research needs to be done.

Although there are many similarities between three out of the four participants regarding EDA and temperature of the tip of the nose, the overall findings and especially the differences between participants suggest that the light might provoke different physical and mood changes in the participants depending on the stimuli and that it is necessary to study each participant carefully to create bespoke design solutions for them, as the level of autism, the level of sensory processing disorder and the intrapersonal characteristics that could influence the psychological associations may differ significantly from one participant to another.

Results also show that, even though each physiological signal, together with the behavioural analysis provides much information on their own, combining the data is an innovative approach which can be more revealing and helpful to understand the positive and negative nuances that describe better the influence of the light and the meaning of what the increase or decrease in physiological signals could indicate. Otherwise stated, talking about increase or decrease of one kind of physiological signal is insufficient for understanding the real impact that the colour has on their body responses.

Consequently, taking into consideration all these findings, a generalisation and subsequent extrapolation of the results might be misleading. For instance, the possible uses of the colours of the light to get a particular feeling should be bespoke based on a combination of the body reactions and the behavioural analysis of every participant.

8.3.2. Does the colour of the light impact in their mood?

The changes in the body responses observed in the previous section suggest that the colour of the light could induce different feelings in the participants. Results from the 3D Mood Box analysis also reveal that there could exist a consistent impact in the mood of the participant regarding the colour of the light most of the times. This finding indicates that the colour of the light could induce different feelings in the participants. This information could be used not only to soothe their anxieties, but also to boost positive feelings, and to encourage relaxation in stressful situations or before going to sleep. Even though some similarities in mood can be observed, the different colours of the light influence every participant differently, emphasising that the environment is perceived differently by every person.

Yellow and Green seemed to induce mainly positive emotions in all the participants. However, many nuances were observed in the feelings the participants could have felt during these coloured lights. On the one hand, in terms of Yellow, the light affected the participants differently in terms of the level of arousal but similarly the temperature of the tip of the nose and the RPM of tics. While Yellow seemed to be a positive arousing factor for Participant F, Yellow had a calming effect in Participant FX. Participant J, though, experienced both positive calming and arousing feelings under Yellow light conditions.

On the other hand, in terms of Green, the light affected the participants differently in terms of the RPM of tics and the level of arousal, but similarly the temperature of the tip of the nose. Feelings observed under Green oscillated around the positive quadrants for Participant F, Participant J and Participant H. This finding indicated that the feelings could not be easily predicted, although they seem to be generally positive. Even though Participant FX also had positive feelings under Green, he also experienced other kinds of feelings such as negative feelings and concentration, indicating that the light could induce other kinds of feelings than only positive. These findings indicate that for all participants except Participant FX, Yellow and Green might be safe lights that will induce positive feelings. However, special attention must be paid to the activities or circumstances in which to turn these lights on. If therapists are seeking a relaxing environment, they should not turn on arousing colours and vice-versa.

Red and Blue seemed to induce mainly positive or mainly negative emotions, depending on the participant. On the one hand, Red seemed to induce high arousing positive feelings in

Participant FX, but it induced negative feelings in Participants F and J (results of Participant H were not conclusive). On the other hand, Blue seemed to induce mainly positive feelings in Participant J, but negative feelings in Participants F and FX (again, results of Participant H were not conclusive).

Most of the literature about the influence of the colour is based on the influence of the colour in performance or physiological signals. Little research has been done about the influence of the colours on people's mood. Despite that, findings on the negative influence of the colour Red on Participant F and Participant J and the positive influence of Blue on Participant J, support the literature which suggests that red colour may induce negative feelings and lack of motivation compared to blue (Elliot, 2015). Results of negative feelings under blue light, observed in Participants F and FX might support the work of Soldat et al. (1997), in which they stated that blue is associated with sadness.

These results indicated that each participant was emotionally affected differently by the colour of the light; thus the findings regarding mood could not be generalised, and new design solutions might not be suitable for all the students at the same time. For example, even though a positive mood tendency was observed under Yellow across all the participants, the light affected differently the level of arousal of the children, which means that the light could be beneficial in some circumstances for some participants, but that, in other circumstances, the light should be avoided. For example, if a calming effect were sought by the therapists, Yellow could be used for Participant FX; however, it should be avoided for Participant F as the light might increase her levels of arousal.

Red, for example, seemed to induce stress and annoyance to Participants F and Participant J. Participant J even showed aggressive behaviour under Red and asked many times to change the colour of the light. However, the results of Participant FX suggested that he felt happy and excited under Red. Again, different natures of feelings were observed under the same environmental conditions, suggesting that every participant perceived the environment and was influenced by it differently.

Although these results are consistent most of the times, results from six sessions might put into question a consistent impact of the light in mood. Results from Participant FX (day 2 and 3), Participant H (days 8 and 14) and Participant J (days 8 and 7) extracted from the daily analysis of the 3D Mood Box (Appendix I) show that the participant experienced same mood under all different light conditions, suggesting that the colour of the light had no effect on the emotional state of the participant or that something happened these days that might have influenced the results and masked the effect of the light.

8.4. How do properties of the light, such as the illuminance, impact in the results?

As observed in Wilms et al. (2016), the properties of the colour can influence body responses. Wilms et al. focused on the hue, saturation and brightness, and defended that the variation of any of these properties influenced the results.

This contribution was revolutionary as most of the research previously done about the topic did not take into consideration the different properties of the colour. Therefore, the results obtained previously might be deceitful unclear and might not be extrapolated to all the types of colour. For example, when other researchers talked about colour Blue, it is not possible to know which kind of blue it was.

In this research, special attention was drawn to these colour properties. Both saturation and brightness were equalised between all the coloured lights, and the only attribute which was changed was the hue. This way, the findings are more specific.

However, a property of the light that was not considered in previous work was the illuminance that provoked the colour in the work surface. In this research, though, measures were taken and the illuminance differed. In other words, the table where the children did the activities was illuminated differently depending on the colour of the light. Unfortunately, the illuminance could not be balanced precisely between colours, firstly, because in order to get the same illuminance, the other properties would need to be changed; and secondly, because the projection and shadow from any object or person near the table could affect the illuminance parameter at any moment. However, if the saturation and the brightness proved to be an influential factor (Wilms & Oberfeld, 2016), it could be expected that properties such as the illuminance and the luminance might influence the results, as well.

Unfortunately, luminance was not measured during the case study but the illuminance levels were measured and noted. In terms of illuminance at the table, White and Fluorescent light had the higher levels (46.2 lux and 45lux respectively), followed by Yellow (33.1lux), Red (22lux), Blue (17.4lux) and finally, Green (12.1lux).

Observing results obtained for tonic EDA, illuminance does not seem to play an essential or consistent role in the levels of tonic arousal for the participants except for Participant FX. Results of tonic EDA collected from Participant FX show that the more illuminance, the less tonic EDA is observed, and the same results are observed for Participant H in terms of Phasic EDA. That is, the highest level of arousal is attributed to the Green which provokes less illuminance (12.1lux), followed by Blue (17.4lux), Red (22lux), and Yellow (33.1lux).

Although these results based on the illuminance might be merely anecdotal, this finding could answer the question why all the participants except Participant FX show many similarities in terms of arousal. While Participant F, Participant H and Participant J were more susceptible to the hue, it would seem that Participant FX might also be susceptible to the illuminance.

Observing results obtained for temperature on the tip of the nose or repetitive behaviour, illuminance does not seem to play an essential or consistent role in the measures of temperature in the nasal area for any of the participants.

Results indicate that the illuminance only seemed to affect the tonic arousal of Participant FX, but none of the other body responses. For this reason, more research should be done on this topic to clear up the influence of the illuminance in the perception and mood of the people.

8.5. Were the activities important? How could the activities influence the results?

One of the primary concerns when starting the experiment was to engage four children with autism with an experimental procedure for at least 15 minutes without stressing them. For this reason, the sessions took place in a familiar environment for the participants. Doing the observations in an unfamiliar environment would have significantly increased the level of anxiety. Although 30 minutes would have been an ideal time per session (because this period would allow us to test more than three colours per session during at least 5 minutes for each light exposure), the attention span of children with severe autism is very limited and spending at least 20-15 minutes with them was already very challenging.

To engage the participants with the tests for at least 15 minutes without altering their levels of stress, it was vital to let them play with whatever they wanted. The ideal situation was that the participants played with the same activity in every session and during the whole session. However, due to the limited attention span, some participants needed to change the activity often. The fact that the participants alternated between different toys was useful because it helped to engage them during the whole 15-minute session, but it was not ideal because each different toy might constitute another variable - or group of variables - to take into consideration in the physiological measures and emotional states. On the one hand, every different toy required different cognitive performance and this might alter the results. On the other hand, every toy might represent different kinds of stimuli (colour and noise) added to the already primary stimuli which is the light being studied.

For example, Participant F would not engage unless she could watch videos from the tablet. The tablet provides an extra light stimulus which might alter the perception of the rest of the light. Nevertheless, the advantage of having Participant F engaged with the tablet was that she only used this tool during all sessions, reducing the variables to consider. That is, every alteration observed of Participant F responded to the same kind of stimuli – and the effect of the tablet on the light colour would be the same for all light conditions. Participant FX needed a particular routine and his routine was to play with three different toys every session. Even though he used to play with three different toys, the toys were always the same across all the sessions and in the same order, although the combination of toy and light was not consistent. Other participants were less consistent. For example, Participant J was unpredictable. While there were days when he engaged during 15 minutes with Lego blocks, on other days he needed other kinds of stimuli and played with different toys and, sometimes, simultaneously. Participant H, however, was very difficult to engage and there were sessions in which he wanted to play with different toys and others in which he only wanted to be with the therapist and refused to do anything.

Although it was known that the different activities were variables that needed special attention, due to the variety of toys and the complexity of understanding the inner mechanisms needed to play with each toy, all of the activities were considered the same. Despite that, this is an inherent characteristic of children with severe autism, and in future research this is a variable which must be taken into consideration.

8.6. What influence of the light is stronger: the biological or the psychological?

It is challenging to identify whether the influence of the colour is linked directly (from a biological point of view) or indirectly (from a psychological point of view) to the participants. Nevertheless, findings on how the colour of the light affects each of the four participants suggest that the physiological signals of Participants F, H and J coincided with findings obtained in studies which focus on the psychological associations, and findings on the influence of the coloured lights in Participant FX coincided with studies which focused on the biological influence of the colour in the body responses.

According to these findings, it might be suggested that, depending on the participant, some individuals are more affected by colour from a biological point of view and others, the majority in this case, are affected by colour from a psychological point of view.

8.7. Is the order of the light sequence important?

As seen in Chapter Two, Wilson (1966) suggested that the order in which the stimuli are presented might be important as EDA responses were different when green was presented before red or when red was presented before green.

The analysis of the influence of the colour of the light is done by comparison, observing which colour induces higher or lower responses of a certain body response. Nevertheless, when performing the daily analysis, some inconsistencies that could be answered by showing that the order has, in fact, an important role in the influence of the colour were found. For example, results of the daily analysis of Participant FX shows how the participant had lower tonic EDA under Blue than White when the participant is exposed to Blue first (Day 7), while the same participant has higher tonic EDA under Blue than White when the participant is exposed to White first (Day 14). These results might seem superficially inconsistent but the reason behind this "inconsistency" might be order of the light exposures. Unfortunately, there was no opportunity to repeat light sequences in the experiment, because of the time limitation of the sessions, and it was not possible to increase the number of sessions, so it was not possible to test all possible orders during the experiment. For this reason, it would be useful to in future research to devise a way to obtain data from different sequences of light colours,

8.8. The importance of the idiosyncrasy of the participants

Results obtained in relation to the different physiological signals and repetitive behaviour analysis emphasise the idea that every individual perceives the environment differently, and, therefore, is influenced by it differently. For this reason, special attention has to be drawn to the context and to the particularities of every individual in order to design the proper space or environmental conditions for them.

Although many similarities in qualitative responses between a few participants might seem very promising, only by studying the physiological signals and behavioural analysis intensely and identifying their differences and nuances, can one interpret how an individual interprets the environment and that this interpretation is not transferable. For this reason, specific results that seem promising due to the similarities only can serve as a starting point for future research.

While Participant F, Participant H and Participant J showed many similarities in terms of EDA and Temperature of the tip of the nose, Participant FX frequently tends to deviate and responds contrarily. First of all, when comparing the influence of fluorescent and LED sources, Participant FX was the only child who was more aroused under White than under Fluorescent Light. Secondly, Participant FX was the only one that presented higher temperature in the nasal area under Fluorescent light, compared to his colleagues, who had similar or higher temperature under White. Thirdly, when comparing the influence of the coloured lights, Participant FX was the only child who was more aroused under Blue than under other coloured lights, while the others were particularly low in terms of arousal under Blue. Fourth, while participants F, H and J showed similar temperature variations depending on the colour of the light (the highest temperature was observed under Green, followed by Yellow and Blue, and finally, Red), the temperatures observed of Participant FX indicated that the colour lights affected him differently (the highest temperature was observed under Yellow, followed by Blue and Red, and finally Green). While Green induced the highest temperatures to 75% of the sample, Participant FX experienced the lowest temperatures.

These differences observed in Participant FX highlight the fact that even though some similarities can be found between the participants, the more significant is the sample, the more prominent will be the range of results because more people might show more types of results. In addition, even though some similarities might be found when observing EDA and nasal temperature when adding more kinds of analysis, the probability of finding similarities would decrease substantially.

For example, EDA has been studied in previous work (Oberfeld, Hecht, Allendorf, & Wickelmaier, 2009; Suk & Irtel, 2010; Wilms & Oberfeld, 2016; Yildirim, Hidayetoglu, & Capanoglu, 2011; Zieliński, 2016) and the similarities found between three out of four participants might support results observed in previous work. Although, the results of Participant FX contradict them.

If we only studied one measure such as EDA, results might seem similar to previous work and might indicate that the individuals had a similar perception of the lights, but it was not until these results were compared to other kinds of physiological signals that the differences in perception and influence arose.

Interestingly, similar similarities and differences between participants were also found when analysing the nasal temperature. These similarities might suggest that the colours of the light and the features of the environment might affect the individuals similarly. However, it was not until the rate per minute of repetitive behaviour and mood interpretations were analysed, that it was possible to observe the amount of between-participant differences in the influence of the light. This finding highlight the fact that perception cannot be just focused on one physiological signal and that the analysis has to be rich and carefully done.

While the similarities between participants can seem promising when intending to create a proper environment for children with autism in general, the differences emphasised that the idea of a shared space for everybody might not suit everybody. This finding supports the work of Delacato (1974), Coulter et al. (2009) and Mostafa (2014) who defended sensory segregation instead of other kinds of segregations.

8.9. Do these findings suggest that the findings can be extrapolated and generalised around the autism spectrum?

No. First of all, the purpose of this research was to evaluate how the colour and source of the light influenced four individuals with autism, to identify the factors and variables that could influence their perception such as their routines, their context and their particular characteristics that make somebody unique, and to work on the beginnings of a way of encoding that understanding in some way that could help inform designers about how it might be possible to create environments for these individuals – as separate examples, but not representatives – of children with autism. Once physiological measures and behavioural analyses were examined, the second purpose of the investigation was to identify the possible emotional state of the children by combining the data collected that is by using only objective and non-invasive data.

It was hypothesised that, even though many studies try to establish general guidelines to design for specific collectives, the individual characteristics of every individual will show the importance of proper bespoke design solutions and the importance of the user of a building. For example, in the matter at hand, as every child suffered differently from sensory processing disorder, and presented a different level of autism, every child would react differently to the light. If the hypothesis is supported, the results from each child would show examples of different reactions and body responses under certain conditions.

The results showed that, although some similarities were found between three out of four participants, there existed many differences in terms of body and behavioural responses and mood between participants; therefore, each child's perception of the environment and its influence on them was also different.

Secondly, the sample of participants and the sample of sessions was small. Further research would be required to have enough information to enlighten if these results might be generalizable to others. However, the fact that a small sample of participants already presents such amount of differences between participants suggests that a generalisation might not be possible in the future, either. Although some similarities were found between participants regarding EDA and nasal temperature, results from these physiological signals also show small differences and also participants who presented opposite results to the others. In terms of repetitive behaviour, results showed that every participant had different results. In other words, these findings can be only considered as preliminary findings relating to the children involved in the experiment. For this reason, the findings from this study suggest that a broad generalisation of these issues might be misleading and inaccurate because of the deep singularities found in each of the children, and it is probable that this would carry forward to other children with autism, meaning that there is no general rule that could be applied to children with autism as a whole. Such a generalisation would not bear in mind many factors implied in the action of processing.

The method proposed in this thesis could be a tool to investigate how an individual perceives the environment, although some changes in the physiological signals might be necessary for different collectives. For example, while EDA and Thermography can apply to everybody, the repetitive behaviour analysis might only apply to people with a particular sensory disorder, so the method should be changed to include other kinds of body responses which would be more representative for a collective study.

8.10. Can the findings of the colour light influence be applied to any stimulus which has the same colour?

The case study addressed the influence of colour in a very particular way, by applying the colour to the light. Having the colour in the light was very useful because this way, the researchers ensured that the participants were experiencing the colour all the time and the amount of light absorbed was always the same.

Other kinds of research use other ways to expose the participants to a particular colour, for example by having the colour in a screen, coloured objects or coloured papers. However, using these methods researchers cannot control the amount of colour exposure that the participant perceives.

The type of stimulus used for this case study was a very particular one, to make use of a lighting system that could be used as a light therapy. For this reason, findings from this case study should not be extrapolated to other situations in which the colour is only applied to an object or cloth.

To know the influence that the colour might have when applied to objects, further research is necessary.

8.11. Limitations of the study

This research has limitations which should be acknowledged. First, the sample of participants is small. Even though the first aims of this research were to see whether it was possible to see differences in mood and body responses depending on the lit environment in which a child with autism is immersed, and such differences are indeed observable in just one participant, when combining the data between different individual participants, it was possible to observe fascinating similarities and differences. However, small samples might produce overestimated effect size evaluations (Ioannidis, 2008). For this reason, it would be worth investigating more participants and to compare their results to see similarities and differences. A more significant sample would reveal whether the results can be generalised or, as it seems to be indicated by the results of this study, the individuality of each participant marks the way that they perceive the light and the results provide a record that is unique to them, in a way that might be informative about potential therapies or environmental circumstances that should be avoided or encouraged under given situations.

Secondly, the duration of the experiment might have been too short. The experiment consisted of two sessions per week for seven weeks, with a total of 14 sessions. In conducting research with children with autism, it is essential to realise that they have particular characteristics which make the inevitably unusual, repeated and continual processes of empirical research activity a real challenge. It is necessary to allow the process to follow their needs and to try to maintain the necessary rigour whilst ensuring that the children are comfortable and not stressed. Due to the condition of the participants, most of them needed the first session to adapt and were absent a few sessions due to illnesses or other reasons. On other days, some of the participants just refused to wear the sensors and did the activities without providing with all the data set needed. This meant that it was not possible to obtain data from the total 14 sessions for any of the participants and that the data gathered was incomplete. According to Maruyama et al. (2014), small samples might lead to confusion and researchers might conclude prematurely that a hypothesis is confirmed or not. If the experiment had more 15-minute sessions, the absences and irregularities would have been compensated, and it would have allowed researchers to test other things like the transitions between colours and to test more repetitions. Moreover, the participants would be more confident and relaxed during the sessions, and it would have been possible to crosscheck more of the results, both within and between participants.

Due to the size of the sample, the results presented in this thesis must be considered as preliminary. However, they do show what happened with these participants in response to changes in lighting and as such they do present a novel insight into how these children responded to these environmental changes. This will be useful in setting up further research, with a more significant sample.

Thirdly, the three-colour sequences were too limiting. It was established to test three colours in every session to have an exposure of each of the three lights for at least 5 minutes in a reasonable time for the children in a single session. It was neither realistic nor possible to propose more than 15-minutes per session due to the condition of the participants. Their attention span is short, and they want to switch locations and activities often. However, an anomaly in the experiment was very revealing. Participant J wanted to switch lights often, and we observed that the more complex sequences of colours we had, experiencing shorter exposures to the lights but experiencing more variety and repetitions, the more informative and exciting the results were for him. This new type of sequences could allow researchers to see consistency or not within the colours and gather more data from different types of light on the same day. Whether this would have worked for other participants is, however, a good question.

In some cases, as seen previously, the daily signals present an upward pattern and the reason for this is as yet unclear. The absence of more repetitions does not help to elucidate the reason for these patterns. More repetitions of colours within the same day and more complex sequences not only would inform about the consistency of the impact that the different lights have on the participant but would also inform if the transition between colours plays a vital role in the influence of the colour and source of the light on the behaviour of a person. That is, we might be able to see if the influence of the light is due only to the source, hue and intensity of the light or if a previous condition is determinant in the behaviour of the participant.

Fourth, it was not possible to replicate the same hue and intensity of the fluorescent lights used in the school with the LED system used during the experiments. For this reason, it might not be possible to extrapolate the results obtained on the influence of the source of the light we observed to all fluorescent systems, but it might provide a hint about how the two different sources influence the participants. It might be worth testing how the current fluorescent system influences their behaviour and take action after testing this.

Participant J adjusted the lighting. In this case we obtained very similar lighting results but it implied a very different action: applying control over the process. This might have a psychosocially important element. However, that Participant J decided to interfere was considered as an opportunity to obtain qualitative information about the likes and dislikes of the participant. This information was very useful for the researchers to triangulate with the physiological and behavioural results obtained. Nevertheless, being conscious about the difference implicit between the light exposures that the participant chose and the light exposures that the researcher imposed, it was vital to perform two kind of analysis for the participant, as seen in Chapter Seven, which were called Analysis A and B.

Another limitation might be the application of this method to other groups than those who have autism. The combination of these three physiological and behavioural data seemed to complement each other in this case and provide useful information about the participants. However, in case researchers want to apply this method with other participants who do not suffer from tic disorders, the third variable should be reconsidered. In this case, the rate per minute of tics seemed pretty obvious to identify and informative for the purpose, given the characteristics of the particular children who participated in the experiment.

CHAPTER NINE – **EPILOGUE**

As discussed in Chapter Two, neuroarchitecture reinforces the idea of the strong relationship between the environment and our brain and how this relationship influences our body responses and behaviour and mood, showing that many different factors of the built environment can be determinant while experiencing it.

This study focused on the colour and source of light. Colour and light are two universal factors present in the environment that influence people in many ways. According to the literature, depending on the colour of the light, people can be more alert or relaxed, can be more productive and efficient in the work environment, and the mood of the individual can be more positive or negative. However, the literature also shows that the influence of the colour of the light can be different depending on many other factors such as psychological associations, age and the gender, among many others (see Chapter two).

Even though the literature showed how people can be affected by the colour of the light differently, there seemed to be a kind of assumption reflected in the literature that the mechanisms behind the process of perceiving the colour and the light were similar across all these participants, and their biological characteristics (gender and age) and their psychological associations played an essential role on the outcomes.

However, despite extensive searches, no information was found that related specifically to how people with sensory processing disorders, such as people with autism, who are broadly known to perceive the environment in a different way from other people, are affected by the colour and source of light. The health and living conditions of people with autism are strongly associated with their experiences of the built environment and they have to deal with the colour and source of the light every day, impacting on their mood and behaviour. Hopefully, if there was a better understanding of how the colour and source of light could influence children with autism's body responses and mood, proper design solutions could be applied to soothe their anxieties and improve their quality of life.

Therefore, the main aim of this study was to develop a method and designing a tool to see how the source and the colour of the light influence the emotional responses of a child with severe autism in order to recommend different light solutions under which they would be both less stressed and happier, and ultimately to improve their welfare. The sub-objectives generated from this general question were focused on determining whether physiological signals or behavioural responses can be measured with non-invasive tools that do not interfere with the performance of the participants under different light conditions, and on exploring how the feelings and emotional responses of the participants can be identified without using subjective questionnaires. Thus, physiological signals such as electrodermal activity (skin conductance) and thermography (temperature of the tip of the nose) and behavioural responses (rate per minute of repetitive behaviour) of four children with autism were monitored during the sessions (Chapter Three) and evaluated individually (Chapter Four and Chapter Five) taking into consideration both different factors of the environment and intrapersonal characteristics of each participant that could impact on the results.

The importance of designing environment and light solutions for children with autism was discussed first (Chapter One) and indicated that a properly designed environment for children with autism could reduce the frustrations which often result in their tantrums, epileptic seizures, aggressive behaviour and health issues such as migraines. Besides, if their relationship with the environment was more fluid and less stressful, they could be more integrated into society.

The first and more obvious outcomes of this study are twofold. The primary challenge and purpose was to develop a method that permitted collecting non-invasive and objective data from children with severe autism and evaluate their mood using only the data collected without using subjective questionnaires, a method that will serve to answer the research question. The method (explained in Chapter Three) was able to collect enough objective data to evaluate each participant's mood. Once the data such as the physiological signals (skin conductance and the temperature of the tip of the nose) and behavioural responses (rate per minute of repetitive behaviour) were collected, they were analysed as described in Chapter Four and the results obtained (Chapter Five) and they were introduced in the 3D Mood Box to interpret the difference in mood under different light conditions (as discussed in Chapter Six and Chapter Seven). The method established that the colour and source of the light does have a substantial impact in the physiological signals, behaviour responses, and mood of the participants.

However, results also showed another essential side-finding. While the method proved that the colour and source of the light affected the physiological and behavioural responses as shown in Chapter Five, and thus the emotional responses of the participants as shown in Chapter Seven, the method also showed that despite a few similarities found, the colour and source of the light affected the responses of every participant differently. In other words, the exhaustive method emphasised the idiosyncrasy of the individual. This is important because this idiosyncrasy is an essential characteristic of people with autism, and it was important that the method could incorporate this.

Some participants showed exactly opposite results, and, even though some participants might show a few similarities in terms of some signals, these similarities did not indicate the same when these signals were combined with others, as indicated in Chapter Five and Chapter Seven. Therefore, although it was confirmed that the colour and source of the light influenced the participants, the method also showed that the influence was different for different participants. Hence, these preliminary results (Chapter Five and Chapter Seven) not only enhanced the idiosyncrasy of the individual but also highlighted the importance of the environment in the welfare of the individual.

Further research is necessary to test the validity of the method and elucidate which other factors could influence these results. The phenotypes of the participants could be determinant in this influence. Biological and psychological components, preferences, medical diagnosis and other disorders that come along with the autistic condition and the sensory processing disorder could have influenced the results, and thus the influence on the colour and source of the light had in the participants.

Consequently, this study is a call to action for architects, neuro-architects and designers who need to pay special attention to the individual and its sensory, physical and vital needs when designing buildings. This study reinforces that the world is composed of neurologically diverse people, and every single person needs to feel safe and comfortable in their homes, workspaces and public buildings. It is the responsibility, the duty, and the privilege of the architects to accomplish this purpose. This study is also a call to action to neuroscientists who research about the influence of the environment in the individual to not reduce the characteristics of the individuals to the minimum, so the individuality of the person is not lost in the process allowing researchers to obtain more fruitful and more accurate results about the participants.

The evidence-based design should be crucial to understand all the variables that can play an important role when designing a project, and the method proposed in this thesis and its possible alterations (Section 8.1) can help with this.

9.1. Contribution to the research field

The study presented in this thesis contributes to the disciplines of architecture and neuroarchitecture.

As mentioned in Chapter Three, this is one of the first studies designing a method to measure the emotional responses of children with severe autism under different light sources and colours based on their physiological signals. The first challenge encountered in developing a suitable method was the nature of the participants, who were highly demanding in some aspects and required more specific care compared to neuro-typical people. However, this challenge was also an opportunity. Creating a new method to gather information from individuals with autism, allowed the development of a stricter and effective method that allowed interpreting the variations of mood of people with autism without subjective self-report questionnaires and only relying on objective data, using non-invasive empathetic tools to measure the body responses of the participants. The strict requirements encouraged the development of a method that might be used with everybody and not only with people with autism. This method showed that it was possible to understand how the different colours and sources of light affected the body responses and mood of the participants effectively.

Nevertheless, one of the advantages of this method was that it was independent of the architectural factor studied (the colour and source of the light), therefore it could also be used to understand how other features of the environment influence the behaviour and mood of the individual. Therefore, the method developed is an innovative method that can be a solution to the problem that researchers encounter when working with vulnerable people, a method that can be used to understand how the built environment and its particular features can impact on people's mood and body reactions using only objective and non-invasive data with demonstrated efficiency. Thus, the information obtained in the future from this method can increase the knowledge about the individual and inform architects and researchers to design environments which would suit better the needs of the individual. Thus a new method on understanding and interpreting the mood may have arrived.

This method also informs architects and neuro-architects about physiological and behavioural data that can be enlightening and complementary to understand the impact of the source and colour of the light in children with autism's body responses and emotional responses. Combining electrodermal activity (skin conductance), thermography of the tip of the nose and repetitive behaviour proved to be more informative than only relying on one kind of body response.

So far, the electrodermal activity has been used to monitor levels of stress of children with autism, but thermography has not been used before to monitor the mood of children with autism in the built environment. This study has shown that these devices can provide vital and precise information about physiological signals and mood of children with autism when they are experiencing different environmental conditions.

Although the method can be used to investigate the influence of any component of the environment, this study focused on one particular feature of the environment: the light. Regarding the influence of the source and colour of the light, this study establishes that both the colour and the source of the light have an essential influence on the skin conductance, the temperature of the tip of the nose and the rate per minute of tics; and also impact on the mood of the individuals by making them feel more relaxed, excited, sad or stressed under different light conditions. This information permits architects and therapists to adopt informed decisions when designing or adapting the environment for these children.

As already mentioned during this epilogue, the difference on the results obtained in this study reinforced that children with autism might perceive the environment differently than neurotypical people, and that, even though the four children belong to the same collective of population and some of them show some similarities, the light affected the physiological and behavioural responses and mood of the participants very differently; therefore, the study emphasised the singularity of every individual showing that the environment influences everybody differently.

Therefore, this study will redound to the benefit of society by raising social awareness among architects and researchers about the vital influence that the environment has in the individual, and the importance of thinking about the particularities of individuals when designing spaces for them, who deserve a proper approach to satisfy their needs and enjoy the most beneficial experience.

9.2. Future work

Due to the originality of the study, the work presented in this thesis can establish the method of future work that would enhance knowledge around the research field. This method should be tested in the future to prove its validity. The influence of the colour and source of the light in children with severe autism can also be investigated in different locations, and the current methodology can be improved to increase the quality of the data collected.

The methodology presented in this study (Chapter Three) can be altered and tested so that future experiments obtain more precise results.

1. The sample of participants could be broadened to see the extent to which the design solutions could be extrapolated (or not).
2. The duration of the case study should be longer than 14 sessions, to be able to recreate more light conditions, different sequences and repeat the sequences in search of consistency in the results.
3. The light sequences should be more complex and include more than three types of lights. It would be interesting as well to repeat lights on the same day in search of consistency if the participants can engage and can participate in the case study for more than 15/20 minutes.
4. The different sequences should include repetitions of a different order of light to elucidate whether the order of the light has an essential role in their mood and physiological and behavioural responses.
5. The case study was carried out in June and July. The case study could be repeated in different times of the year such as winter, or could be extended until February, to see how the colour and source of the light affect the mood of children with autism who are more keen to suffer from seasonal affective disorders.
6. Hue, saturation, intensity and illuminance were properties of light controlled during this case study. Luminance would reflect the presence of different materials on the surface, distance from the light source, among others, and would represent more carefully how much and what kind of light might be reaching the retina. It is rarely

used, but perhaps it should be an essential element of analysing light in terms of perception.

7. The only property of the coloured light examined in this case study was the hue. Variations in the saturation and intensity can also be included in future research to see how the different properties affect the mood of children with autism.
8. As seen in Chapter Five, Section 5.4, the tics of the participants were measured as occurrences. However, if it becomes possible to measure the intensity and meaning of every tic, it would be interesting to see whether the results would be different.

The methodology presented in this study (Chapter Three) can be altered as well so that future experiments can examine the emotional responses and body reactions of children with autism in different environments that can be challenging for them for any reasons such as their bedrooms, the dining room and workspaces.

This research proposes a method and a tool to evaluate and understand the implications of the variations of the physiological and behavioural reactions of children with severe autism in their emotional state. These reactions have been linked to positive or negative emotional responses and feelings. However, this research does not try to evaluate feelings or emotions per se, but to propose a method that has the potential to do it in the future. Future research on feelings and emotions would be necessary to determine exactly what kind of feeling or reaction the participant might be experiencing.

One of the main objectives of identifying the mood of the children under different light conditions was to use a different kind of light in different situations to achieve positive outcomes. For example, the calming lights could be used to soothe the anxieties of the children when they feel overwhelmed or have tantrums, the activating lights could be used when the students feel sad or apathetic, and the concentration lights could be used to boost concentration. The light could act as a mood/behaviour changer as seen in previous work (Kuijsters, Redi, Ruyter, & Heynderickx, 2015; Sleegers et al., 2012). Further research should be necessary to know if the colour of the light can improve their mood when they already feel sad and frustrated and make them relax, that is the colour and source of the light has the power to soothe the anxieties of the participants in extreme situations. It would also be very beneficial if further research tries to elucidate whether certain types of light can improve their academic performance and concentration while doing tasks, as well. If the colour of the light seems to improve the mood when the participants feel already sad and anxious, dynamic lighting solutions could be designed to improve their mood when necessary.

As previously mentioned in Chapter Three, the fluorescent lighting system installed in the school could not be studied and its influence in mood could not be compared to the influence of other light sources like LED due to the impossibility to obtain the same light properties on the LED lighting system designed (composed by only three LED bulbs). If the lighting system used in the study was more complex and had more bulbs or more powerful LED bulbs which provided more intensity, the comparison between the current fluorescent lighting system and a similar LED lighting system could be done. Therefore, it could be established whether the fluorescent light is damaging to the children provoking tantrums and migraines as the therapists suggest.

Hopefully, if the light proved to have the power of changing the mood and behaviour of the participants, as previously seen in the literature shown in Chapter Two, and it could guide not only their behaviour and mood but also their performance, children with autism could be more integrated into society.

Further research could investigate the extent to which the methodology presented could also be altered and used to examine the effect of other architectural factors in their physiological signals and mood. As previously mentioned, the method proposed can be independent of the variable studied in this case study, the source and the colour of the light. According to the therapists' concerns, other possible matters of study could be the patterns on the carpet that seem to provoke anxiety on the students, the different levels of environmental noise, the patterns and colour of the walls, the furniture and decoration of the academic environment, among others. Instead of using the results obtained from these new researches to adapt to the environment flexibly, as the light can do, the results obtained from these new studies could inform about the final design and architectural solutions.

The methodology presented can also be altered and used to examine the effect of the colour and source of the light, or other architectural factors as previously mentioned, in the physiological and emotional responses of typically developed people or people with other disorders or diseases such as dyslexia, dementia or Alzheimer. One of the advantages of this methodology is that it permits the identification of emotional states or emotional tendencies by only using objective and quantitative data. Although self-report questionnaires are a tool very broadly used with neuro-typical participants, it is a tool that can provide subjective, and sometimes, misleading information. For this reason, applying this method additionally to other kinds of participants can be highly useful to avoid subjective information that could interfere in the results. Nevertheless, it is vital to bear in mind that, if the method is applied to other kinds of individuals, the physiological measures studied should be reconsidered. While electrodermal activity and the thermography of the tip of the nose seemed to be two physiological measures that could monitor effectively any participant, the election of repetitive behaviour as a third measure was specially selected for the children with autism who participated in the case study, who suffer from tics disorders. Measuring the rate per minute of repetitive behaviour on these four participants was straightforward and non-invasive. Besides, the election of the rate per minute of tics as a variable had two other reasons: first, the rate per minute of tics could be a clear indicator of stress in the children and, second, tics are a characteristic that impede the children to have a healthy life due to its severity, so finding a light condition that reduced the number of tics per minute was another side-objective of this study. However, even though this indicator was very useful with children with autism, this indicator should be changed by another physiological signal or behavioural response more suitable for the kind of participant studied.

Leaving aside any possible alteration of the methodology to improve the quality of the data collection in the future, there exists other kinds of data which was collected during this case study that could contribute with more information about the influence of the colour and source of the light on the participant if the situation would have required it. On the one hand, the attention span could be measured from the video recordings collected. Measures from the attention span can show if there is any light in particular who helps the student to remain focus on the activity. On the other hand, the video recordings from the third camera located in front of the participant (See Chapter Three) could be analysed and processed with a facial recognition software to detect smiles and other facial expressions that could help to understand the mood of the participant and how the participants exteriorise them, and see if there exists any significant prevalence under any light in particular.

There is a lot to do in the field of neuroarchitecture, that should consider all types of brains and individuals, and their relationship with the environment. Further research can help to understand why the relationship with the built environment and people with autism and sensory processing disorders can sometimes be so harsh that affect their mood and health negatively and inform architects and designers to design in consequence. According to Zimmermann in his paper, The nervous system in the context of Information Theory (1989), the brain of a neuro-typical person can process around 40bits/s of visual stimuli in the state of conscious awareness. However, the brain can process 10^7 bits/s in the preconscious readiness state. Considering "bits" as a piece of information, these values suggest that neuro-typical people do not process sensory inputs that the preconscious brain considers to be unnecessary (such as small defects on the pattern of a brick wall). Even though Zimmermann does not mention autism, it might be interesting to consider whether the conversion of information from ‘preconscious readiness’ to ‘conscious awareness’ might be challenging for people with autism and how they do this conversion. If this were the case, it might help to explain why there seems to be hypersensitivity (or hyposensitivity, as well) to environmental stimuli and the inner mechanisms involved, which provoke reactions such as tantrums and migraines, due to the overload of stimulation.

GLOSSARY

3D Mood Box is a model proposed for this thesis which consists of a three-dimensional box composed of the physiological and behavioural information obtained of a participant to understand and identify the mood and emotional tendencies of the participant under different environmental conditions.

Autistic Spectrum Disorder (ASD), according to the National Autistic Society, commonly known as ‘Autism’, but including other conditions, such as Asperger Syndrome, is a lifelong, developmental disorder that influences how a person communicates with and relates to other individuals, the social imagination, and how they experience the world around them. 1 in 100 children in the United Kingdom is affected by ASD.

Behavioural responses are responses that can be extracted from the behaviour of a person.

Biological influence of the light, or direct influence of the light, when the colour influences the body responses without cognitive intermediary response. For example, the wavelength of the colour is observed by the body through the skin or the eyes, producing an effect on the physiological responses (Kaiser, 1984).

Brightness refers to the sensation of luminosity or darkness in the room. Brightness is the term used for the subjective impression of the luminance.

Colour of the light is composed by the hue, the saturation and the intensity of the light.

Colour temperature (CT) refers to the sensation of warmth (yellow, orange and red tones) and coolness (green and blue tones) of the white light. It is measured in Kelvins; the more CT the light has, the cooler it is, and vice versa: cool colours (bluish) present high CT over 5000K; warm colours (yellowish) present low CT around 2700-3000K.

Electrodermal activity (EDA), also known as Galvanic Skin Response (GSR) or **skin conductance response (SCR)**, is used to obtain data on the autonomic changes in the electrical properties of the skin from the variations of sweat which come from the sweat glands. As the sympathetic nervous system controls sweating, EDA is associated with emotional and cognitive processing and is an essential and objective variable in psychological science. EDA measures changes in arousal and can inform cognitive states and emotions such as stress, excitement and fear, among others (S. D. Kreibig, 2009). It is measured in MicroSiemens (μS).

Fluorescent light is a light source, usually in tubes, that produces light when the mercury vapour inside the tube is excited by the electric current.

Hue of the light is the colour itself determined by its dominant wavelength. It is expressed in a range from 0% to 100% being 0% the longest visible wavelength colour (reddish) and 100% being the shortest visible wavelength colour (bluish). Phillips Hue App permits to program up to 65535 different hues. For example, colour Blue used for the case study was link to a hue of the 60% (39410/65535).

Illuminance refers to the luminous flux which falls on a particular surface (affected by all the elements which surround the specific surface) and it is measured in Lux (lux).

Intensity, also referred to as brightness, refers to the mix of white and black in the colour. The more white has been added, the more intense and brighter it is; the more black has been added to the colour, the darker. The intensity is then defined relative to a reference white and ranges from 0 to 100, measured in %, where 100% represents the amount of white compared to the 0% of black.

LED, or Light-Emitting Diode, is a light source that emits light when an electric current passes through it. They can produce a great amount of colours.

Light, or visible light, is a visible electromagnetic radiation with wavelengths between 750 nanometers and 380 nanometers, but for the purposes of this thesis, light refers to the illumination derived from a source of light, that can be artificial like lamps or natural like the Sun.

Light sequence is the premeditated order in which the different kinds of light were set in the sessions of the case study.

Light source is a source of illumination. Artificial light sources can be halogens, LED and Fluorescent lights, among others.

Luminance is luminous flux emitted from a source or surface, in a certain angle, detected by the human eye. It is measured in candela per square meter (cd/m2).

Mired, micro reciprocal degree, measurement unit to express Colour Temperature. Philip Hue App permits creating 500 different mireds.

Metaballs are the spheres associated to every dataset of information introduced in the 3D Mood Box. Metaballs tend to coalesce with others depending on the proximity between different metaballs, creating bigger and more complex metaballs.

Mood or emotional state is a temporary feeling or state of mind.

Motor tics are involuntary, abrupt, rapid, repetitive movements.

Neuroarchitecture studies the relationship between the brain processes and the architectural environment and their influence in emotional and physical health of the individuals, through the contributions made by neurosciences. www.anfarch.org

Perception awareness and recognition of the elements of the environment using the senses. The process of perception goes: <u>Environment</u> (stimuli/"situation") is perceived by <u>Sensorial Pathways (Senses)</u> and this information is sent to the brain, <u>Cortex (neurons)</u>, where the <u>Perception,</u> processing by the mind of the multiplicity of the multisensorial data, including past lived experience, takes place, provoking an <u>Action</u> that could be physiological or physical or cognitive. This process develops a <u>new idea/perception</u> of the environment/stimuli and this new perception <u>*changes the environment/stimuli*</u> (or the idea of it). Therefore, the individual faces again a <u>new and renovated environment/stimuli</u> and the process start again (Adhitya & Tyler, 2019).

Physiological signals are biologic responses generated by the physiological, physical and chemical processes of the body.

Phonic tics are involuntary, abrupt, rapid, repetitive sounds.

Psychological influence of the light, or indirect influence of the light, is when any cognitive association is done when perceiving the colour (Kaiser, 1984).

Repetitive behaviour or tics are rigid, involuntary, repetitive, stereotyped and inappropriate movements, repetitive use of language, repetitive manipulation of objects, specific attachment to objects and repetitive self-injurious behaviours, among others

RPM of tics is the rate per minute of tics.

Saturation is the purity of the hue. If the colour is 100% pure, 100% saturated, it means that the colour does not have any addition of grey (%).

Sensory processing disorder (SPD) is a disorder characterised by its inability to interpret and organise the stimuli from the environment because these stimuli are not (well) detected and translated differently by the nervous system. Differences in the structures of the nervous system might influence this inability to process the stimuli correctly.

Skin conductance (See Electrodermal activity)

Phasic EDA, or skin conductance responses (SCRs) or the number of phasic peaks, reflects quicker changes associated with stimulus-specific or non-specific responses.

Thermography is a non-invasive technique employed in psychology to study autonomic physiological responses to emotions. The temperature of the skin brings essential information about nonverbal behaviour, which is not subject to subjective interpretations as are some other measures.

Thermal picture is a picture that stores all the thermal information of an individual.

Tonic EDA, or skin conductance level (SCL), reflects slow physiological changes in the EDA response in long-term situations.

Wavelength is the distance between two successive crests of an electromagnetic wave, measured in nanometers. The wavelength is different for every colour: violet/blue has the shorter wavelength, followed by green, then yellow and finally red colour has the longest wavelength.

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APPENDICES

APPENDIX A. ETHICS APPROVAL

UCL RESEARCH ETHICS COMMITTEE
OFFICE FOR THE VICE PROVOST RESEARCH

UCL

16th March 2018

Professor Nick Tyler
Department of Civil, Environmental and Geomatic Engineering
UCL

Dear Professor Tyler

Notification of Ethics Approval with Provisos
Project ID/Title: 9317/002: Methods test for experimental design of environmental features

Further to your satisfactory responses to my comments, I am pleased to confirm in my capacity as Joint Chair of the UCL Research Ethics Committee (REC) that I have ethically approved your study until 16th March 2019.

Ethical approval is subject to the following conditions:

Notification of Amendments to the Research
You must seek Chair's approval for proposed amendments (to include extensions to the duration of the project) to the research for which this approval has been given. Ethical approval is specific to this project and must not be treated as applicable to research of a similar nature. Each research project is reviewed separately and if there are significant changes to the research protocol you should seek confirmation of continued ethical approval by completing an 'Amendment Approval Request Form'
http://ethics.grad.ucl.ac.uk/responsibilities.php

Adverse Event Reporting – Serious and Non-Serious
It is your responsibility to report to the Committee any unanticipated problems or adverse events involving risks to participants or others. The Ethics Committee should be notified of all serious adverse events via the Ethics Committee Administrator (ethics@ucl.ac.uk) immediately the incident occurs. Where the adverse incident is unexpected and serious, the Joint Chairs will decide whether the study should be terminated pending the opinion of an independent expert. For non-serious adverse events the Joint Chairs of the Ethics Committee should again be notified via the Ethics Committee Administrator within ten days of the incident occurring and provide a full written report that should include any amendments to the participant information sheet and study protocol. The Joint Chairs will confirm that the incident is non-serious and report to the Committee at the next meeting. The final view of the Committee will be communicated to you.

Final Report
At the end of the data collection element of your research we ask that you submit a very brief report (1-2 paragraphs will suffice) which includes in particular issues relating to the ethical implications of the research i.e. issues obtaining consent, participants withdrawing from the research, confidentiality, protection of participants from physical and mental harm etc.

In addition, please:

- ensure that you follow all relevant guidance as laid out in UCL's Code of Conduct for Research: http://www.ucl.ac.uk/srs/governance-and-committees/resgov/code-of-conduct-research
- note that you are required to adhere to all research data/records management and storage procedures agreed as part of your application. This will be expected even after completion of the study.

With best wishes for the research.

Yours sincerely

Professor Michael Heinrich
Joint Chair, UCL Research Ethics Committee

Cc: Nuria Hernandez Rivera, PhD student researcher, UCL Department of Civil, Environmental and Geomatic Engineering

APPENDIX B. INFORMATION SHEET

Participant Information Sheet for Parents/guardians/carers of participants
UCL Research Ethics Committee Approval ID Number: **9317/002**

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

Title of Study:
Could light colour change children with autism mood and behaviour in the academic environment?

Department:
Civil Environmental and Geomatical Engineering

Name and Contact Details of the Researcher(s):
Nuria Hernandez Rivera,

Name and Contact Details of the Principal Researcher:
Nick Tyler,

1. **Invitation Paragraph**

   We would like to invite your child to participate in this research project. ***This study is part of a PhD research project which is trying to improve understanding about how people with autism interpret and are affected by the environment, specially the colour and type of the light. The particular exercise in question here is an experiment to help us determine whether the participant's behaviour and mood change according to the colour and type of the light.***

   You and your children should only participate if you want to. Choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear, or if you would like more information. Before you decided it is important for you to understand why the research us being done and what participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

2. **What is the project's purpose?**

   As you may know, most of the people with autism suffer from sensory processing disorder. This interferes with their ability to process some of the external stimuli from their close environment correctly. As a result, they may feel uncomfortable and insecure, in addition to being more likely to have health problems, such as stress and headaches, derived from this difficulty. After having done a pilot, we realized that the light (type and different colours of it) is one of the features of the environment that affect the behaviour the most. Some participants showed significant difference on behaviour depending on the colour of the light. This experiment aims to understand how lighting affect people who have sensory processing issues. This would be very useful in order to be able to create or propose guidelines for the design in architecture for people with autism and to evaluate whether these new designs are effective.

3. **Why have I been chosen?**

1

Your child has been selected to take part on the light experiment. (S)He has been selected because (s)he participated on a previous Pilot which took place last year and enjoyed the activity and showed significant differences on behaviour regarding the colour of the light. Three more children have been selected for this study.

4. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. You can withdraw at any time without giving a reason and without it affecting any benefits that you are entitled to.' if you decide to withdraw you will be asked what you wish to happen to the data you have provided up that point.

5. What will happen to me if I take part?

This project will take place in Prior's Court (Hermitage,Thatcham, Berkshire RG18 9NU). If you and your child agree to participate, your child would take part in a simple activity which take place in a sensory room designed for this research. Your child will do the activity individually. We will ask the child to do a simple task (one which (s)he is already used to doing) (This will be assessed by their caregivers and teachers). In the course of the exercise, we will run the tasks under different lighting conditions. By doing this, and observing his/her reactions, we will be able to know if they change their behaviour due to the environment.

In order to understand the reactions of the children, and to see if they feel happy or not about different factors of the room, the sessions will be recorded with a video camera. In addition, the children will be monitored with a bracelet which analyses their skin conductance. If the child does not want to wear the bracelet, (s)he will be able to do the experiment without the bracelet. This information will provide physiological signals which will enable us to have an objective indication to see if they are stressed or relaxed. These sensors are not invasive (they are rather like a wristwatch) and will not hurt them.

This activity will be repeated up to 14 times on different days so that we can compare the results. The caregivers and research team will always supervise the activity together.

All the children's reactions will be discussed with their caregivers and teachers in order to help interpret the data. We will be taking notes about their choices, and using their responses to determine which type of light affect them and how and which ones will need to be changed in order to make them feel more comfortable in the future.

To keep this study interesting for your child we will present it as a game. You may be present during the study. However, the children will be always accompanied by a caregiver or a teacher they already know. Nevertheless, you or your child are free to stop the study at any time.

The sessions will normally last up to 30 minutes (including breaks). If we notice that your child is not comfortable with the task, we will stop it until (s)he feels better, or if, necessary, indefinitely.

We will not be scoring your child's responses as 'good' or 'bad', and we will not be able to give feedback on your child's individual performance. However, once the study is complete, you will be invited to view the final report, including anonymized data from all participants.

6. Will I be recorded and how will the recorded media be used?

The audio and/or video recordings of your child's activities made during this research will be used only for analysis and for illustration in conference presentations and lectures. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.

7. What are the possible disadvantages and risks of taking part?

The only disadvantage of this study would be that the child would not feel comfortable with a type of light. In case the child does not want to have a specific type of light, we will not use it until the participant wants to or, if necessary, indefinitely.
Any unexpected discomforts, disadvantages and risks to participants, which arises during the research, will be noted immediately and taken into consideration for future sessions.

8. What are the possible benefits of taking part?

Whilst there are no immediate benefits for those people participating in the project, it is hoped that this work will help us to understand the relationship between the participant and the environment. This information will allow architects, designers and teachers, among others, to bespoke architectural solutions for the children in the academic environment. The results from this research will also inform future research.

9. What if something goes wrong?

If the participant feels the researchers were not respectful or professional during the task, you can raise a complaint. If something serious occurring during or following their participation in the project, you can raise a complaint as well.

In case you want to raise a complaint, you can contact Nick Tyler (   ). However you should also know that if your complaint has not been handled to their satisfaction by the principal researcher, Nick Tyler, you can contact the Chair of the UCL Research Ethics Committee

10. Will my taking part in this project be kept confidential?

All the information that we collect about you during the course of the research will be kept strictly confidential. You will not be able to be identified in any ensuing reports or publications.

Video recording and electro dermal activity results will be held about your child and only professionals related to Prior's Court and academic researchers will have access to it. No external agency is being used to transcribe data.

11. Limits to confidentiality

Please note that assurances on confidentiality will be strictly adhered to unless evidence of wrongdoing or potential harm is uncovered. In such cases the University may be obliged to contact relevant statutory bodies/agencies.

12. What will happen to the results of the research project?
The results will be only disseminated for publication in articles and presented within a PhD thesis within the next two years. In case the results are published, you can obtain a copy of the published results and we will let you know how obtain the copy. Your child will not be identified in any report or publication.

The information will be storage for the next two years.
The project might be used for additional or subsequent research.

13. Data Protection Privacy Notice

Notice:
The data controller for this project will be University College London (UCL). The UCL Data Protection Office provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk. UCL's Data Protection Officer is Lee Shailer and he can also be contacted at data-protection@ucl.ac.uk.

Your personal data will be processed for the purposes outlined in this notice. The legal basis that would be used to process your personal data will be the provision of your consent. You can provide your consent for the use of your personal data in this project by completing the consent form that has been provided to you.

***Your personal data will be processed so long as it is required for the research project, which will be two years.** If we are able to anonymise or pseudonymise the personal data you provide we will undertake this, and will endeavour to minimise the processing of personal data wherever possible.*

If you are concerned about how your personal data is being processed, please contact UCL in the first instance at data-protection@ucl.ac.uk. If you remain unsatisfied, you may wish to contact the Information Commissioner's Office (ICO). Contact details, and details of data subject rights, are available on the ICO website at: https://ico.org.uk/for-organisations/data-protection-reform/overview-of-the-gdpr/individuals-rights/

14. Who is organising and funding the research?
La Caixa Foundation, Spain.

15. Contact for further information
In case you need further information, do not hesitate to contact me, Nuria Hernandez, via email at

You will be given a copy of the information sheet and a signed consent form to keep and remember to thank your child taking part in the project.

Thank you for reading this information sheet and for considering to take part in this research study.

4

APPENDIX C. CONSENT FORM

CONSENT FORM FOR PARENTS/GUARDIANS OF PARTICIPANTS IN RESEARCH STUDIES

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: Could light colour change children with autism mood and behaviour in the academic environment?
Department: Civil Environmental and Geomatical Engineering
Name and Contact Details of the Researcher(s): Nuria Hernandez Rivera,
Name and Contact Details of the Principal Researcher: Nick Tyler,
Name and Contact Details of the UCL Data Protection Officer: Cerine Yudin,
This study has been approved by the UCL Research Ethics Committee: Project ID number: 9317/002

Thank you for considering taking part in this research. The person organising the research must explain the project to you before you agree to take part. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

I confirm that I understand that by ticking/initialling each box below I am consenting to this element of the study. I understand that it will be assumed that unticked/initialled boxes mean that I DO NOT consent to that part of the study. I understand that by not giving consent for any one element that I may be deemed ineligible for the study.

		Tick Box
1.	*I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information and what will be expected of my child. I have also had the opportunity to ask questions which have been answered to my satisfaction *[and would like to take part in (please tick one or more of the following)* - *The task which will take place in Prior's court in which the light conditions will be changing* - *The monitoring of the arousal with the skin conductance sensors*	
2.	*I understand that I and my child will be able to withdraw my data up to *4 weeks after the task.*	
3.	*I consent to the processing of my child's personal information *such as video recordings and arousal activity,* for the purposes explained to me. I understand that such information will be handled in accordance with all applicable data protection legislation.	
4.	**Use of the information for this project only.** The information will be used only for academic purposes and shared with Prior's Court professionals. *I understand that all personal information will remain confidential and that all efforts will be made to ensure my child cannot be identified. I understand that the data gathered in this study will be stored anonymously and securely. It will not be possible to identify my child in any publications. (a) I request that my (my child's) comments are presented anonymously.	
5.	*I understand that the information gathered may be subject to review by responsible individuals from the University for monitoring and audit purposes.	
6.	*I understand that the participation of my child is voluntary and that my child is free to withdraw at any time without giving a reason. I understand that if my child decide to withdraw, any personal data (s)he has provided up to that point will be deleted unless I agree otherwise.	
7.	I understand the potential risks of participating and the support that will be available to her/him should my child become distressed during the course of the research.	
8.	I understand no promise or guarantee of benefits have been made to encourage you to participate.	
9.	I understand that the data will not be made available to any commercial organisations but is solely the responsibility of the researcher(s) undertaking this study.	
10.	I understand that I or my child will not benefit financially from this study or from any possible outcome it may result in in the future.	
11.	I understand that my child will not be compensated for the portion of time spent in the study.	
12.	I agree that the anonymised research data of my child may be used by others for future research. [No one will be able to identify you when this data is shared.]	
13.	I understand that the information my child has submitted will be published as a report and I wish to receive a copy of it. Yes/No	

14.	I consent to my child's task being audio/video recorded and understand that the recordings will be: - Stored anonymously, using password-protected software and will be used for training, quality control, audit and specific research purposes. To note: If you do not want your participation recorded you cannot take part in the study.	
15.	I hereby confirm that I understand the inclusion criteria as detailed in the Information Sheet and explained to me by the researcher.	
16.	I hereby confirm that: (a) I understand the exclusion criteria as detailed in the Information Sheet and explained to me by the researcher; and (b) I do not fall under the exclusion criteria.	
17.	I agree that the GP of my child may be contacted if any unexpected results are found in relation to my health.	
18.	I have informed the researcher of any other research in which my child is currently involved or has been involved in during the past 12 months.	
19.	I am aware of who I should contact if I wish to lodge a complaint.	
20.	I voluntarily agree to take part in this study.	
21.	Use of information for this project and beyond will be stored up to the finalisation of the research. The personal data will be destroyed within the next two years. I would be happy for the data I or my child provide to be archived at secured laptops and hard drives. I understand that other authenticated researchers will have access to pseudonymised data. UCL network, *encrypted USB stick, *encrypted laptop etc. Data collected in the research studies will not be linked to individuals' contact details, and will be stored in an anonymized format. Only the experimenters will have access to the records and they will be stored in a password-protected format, and further that all data analysis will be conducted on anonymized records.	
	*Advanced Encryption Standard 256 bit encryption which has been made a security standard within the NHS)	
22.	**Overseas Transfer of Data** *I understand that the personal data of my child will NOT be transferred.*	

If you would like your contact details to be retained so that you can be contacted in the future by UCL researchers who would like to invite you to participate in follow up studies to this project, or in future studies of a similar nature, please tick the appropriate box below.

	Yes, I would be happy to be contacted in this way	
	No, I would not like to be contacted	

Name of participant	Date	Signature
Name of witness (If applicable)	Date	Signature

APPENDIX D. PERMISSION LETTER FROM PRIOR'S COURT

Prior's Court
Building a future for people with autism

Ms Nuria Hernández Rivera
University College London

14 March 2018

Dear Nuria

Following our conversations about the next stages of your research project at UCL investigating the impact of light, shadow and colour on the behaviours of autistic children, I can confirm that Prior's Court are willing to partake in the research in the way specified in the e mails between ourselves. Specifically we will make staff and children available to take part in the research and before the children take part we will ensure all parental permissions are secured.

We look forward to working with you and to see how the outcome of the research may help us provide even better outcomes for the young people at Prior's Court.

Yours sincerely

M W Robinson
CEO
Prior's Court Foundation

Ofsted Outstanding Provider
IQM Inclusion Quality Mark
INVESTORS IN PEOPLE
Arts Council England
Artsmark Gold Award Awarded by Arts Council England

Hermitage, Thatcham, Berkshire
RG18 9NU United Kingdom
Tel:
Fax:
Email:
Web: www.priorscourt.org.uk

APPENDIX E. PHENOTYPES OF THE PARTICIPANTS

Phenotypes of Participant F:

- **Level of IQ:** Not available
- **Communication:**
  - Significantly impaired language
  - Uses PECS to increase her ability to communicate effectively
- **Verbal/Non-verbal:** Non-verbal
- **Diagnosis:**
  - ASD
  - Severe Learning Difficulties
  - Hyperphagia
  - Tourette's Syndrome
  - Significant sensory difficulties
- **Other Medical Issues:**
  - Headaches
  - Obesity with insulin resistance
  - Precocious Puberty
- **Description of Autism Profile:**
  - Adaptive Behaviour - Adaptive Behaviour Assessment System – 2nd Edition (ABAS II)
  - Conceptual Domain: Standard score: 49 (< 0.1st percentile)
  - Social Domain: Standard score: 55 (0.1st percentile)
  - Practical Domain: Standard score: 40 (<0.1st percentile)
  - General Adaptive Composite: standard score – 40 (< 0.1st percentile.
  - It is estimated that in age equivalent terms Freya is below the level of an average 2-year-old. Her adaptive behaviour is at a level which is considered to be severe - requiring extensive and pervasive support.
- **Instrument to Diagnose ASD:** not available

Phenotypes of Participant FX:

- **Level of IQ:** Not available.
- **Communication:**
    - Participant uses some limited spoken language, mainly single words and some short learnt phrases alongside symbols (PECS/GRID).
    - Participant uses a Grid a communication device. PECS is Felix's backup method of communicating if the GRID is not working
- **Verbal/Non-verbal:** Verbal. Participant has echolalia, sometimes uses to communicate his needs, has very little spontaneous language.
- **Diagnosis:**
    - Severe ASD
    - Profoundly atypical sensory processing difficulties
    - Severe language delay
    - Learning Difficulties
    - ADHD-type behaviours
- **Other Medical Issues:**
    - Sleep disorder
- **Description of Autism Profile:** Not available
- **Instrument to Diagnose ASD:** not available

Phenotypes of Participant H:

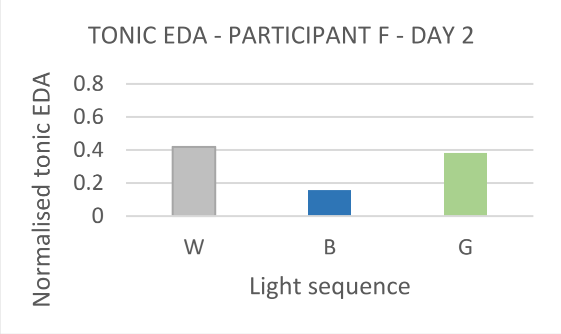
- **Level of IQ:** Not available
- **Communication:**
  - Speech & Language Disorder with associated social communication difficulties
  - Severely Delayed & Disordered Speech, Language& Communication
- **Verbal/Non-verbal:**
  - 50% verbal / 50% Proloque2go communication software to support his use of spoken language- using an iPad.
  - Main method of communicating is verbal, although it can be unclear.
- **Diagnosis:**
  - ASD
  - Klinefelter Syndrome
  - ADHD
  - Speech & Language Disorder with associated social communication difficulties
  - Learning disability
- **Other Medical Issues:**
  - Epilepsy
  - Asthma
  - Possible Migraines
- **Description of Autism Profile:**
  - Assessment on Vineland II on the Maladaptive Behaviour Scale - scored the highest level for such behaviours both internalising & externalising and at the Clinically Significant level.
  - Assessed using parents' version of Vineland II scores were exceptionally poor for adaptive behaviour in all domains. The lowest was within the socialising domain with a percentile score of <0.1.
- **Instrument to Diagnose ASD:** Autism Diagnostic Observation Schedule (ADOS)

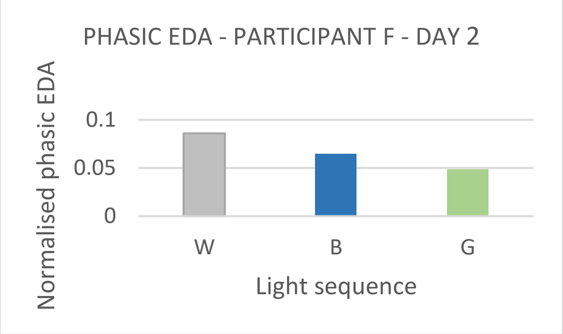
Phenotypes of Participant J:

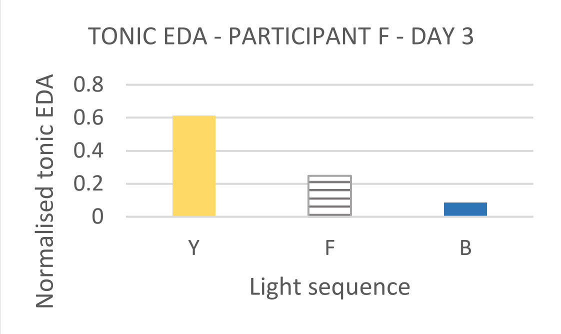
- **Level of IQ:** Developmental age estimated to be 3 years & 6 months.
- **Communication:**
    - Severe Specific Receptive & Expressive Language Difficulties
    - Benefits from the use of visuals to support him to make choices
- **Verbal/Non-verbal:** Verbal
- **Diagnosis:**
    - ASD
    - Social Communication Difficulties
    - Learning Difficulties
- **Other Medical Issues:** Not available
- **Description of Autism Profile:** Not available
- **Instrument to Diagnose ASD:** Not available

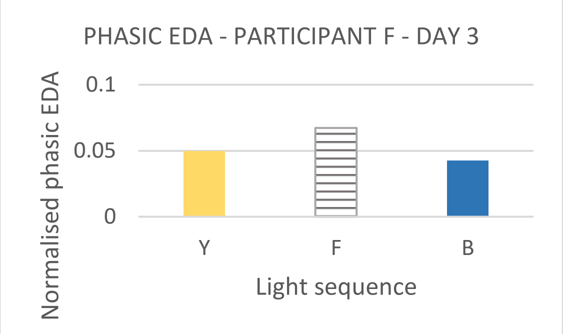
APPENDIX F. RESULTS – DAILY ANALYSIS ELECTRODERMAL ACTIVITY

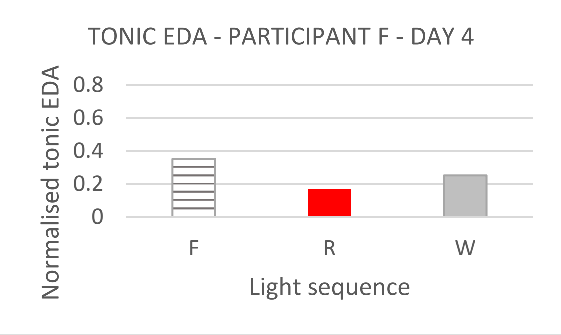
Participant F:

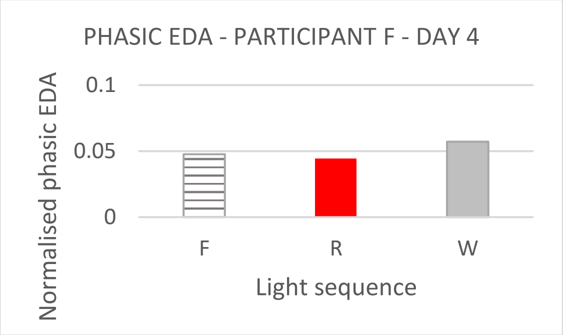


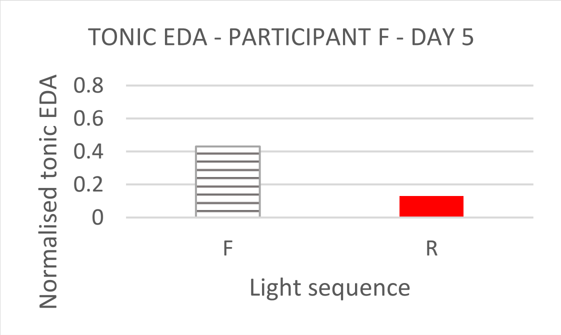


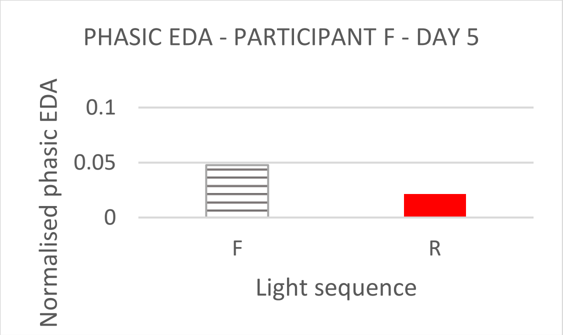


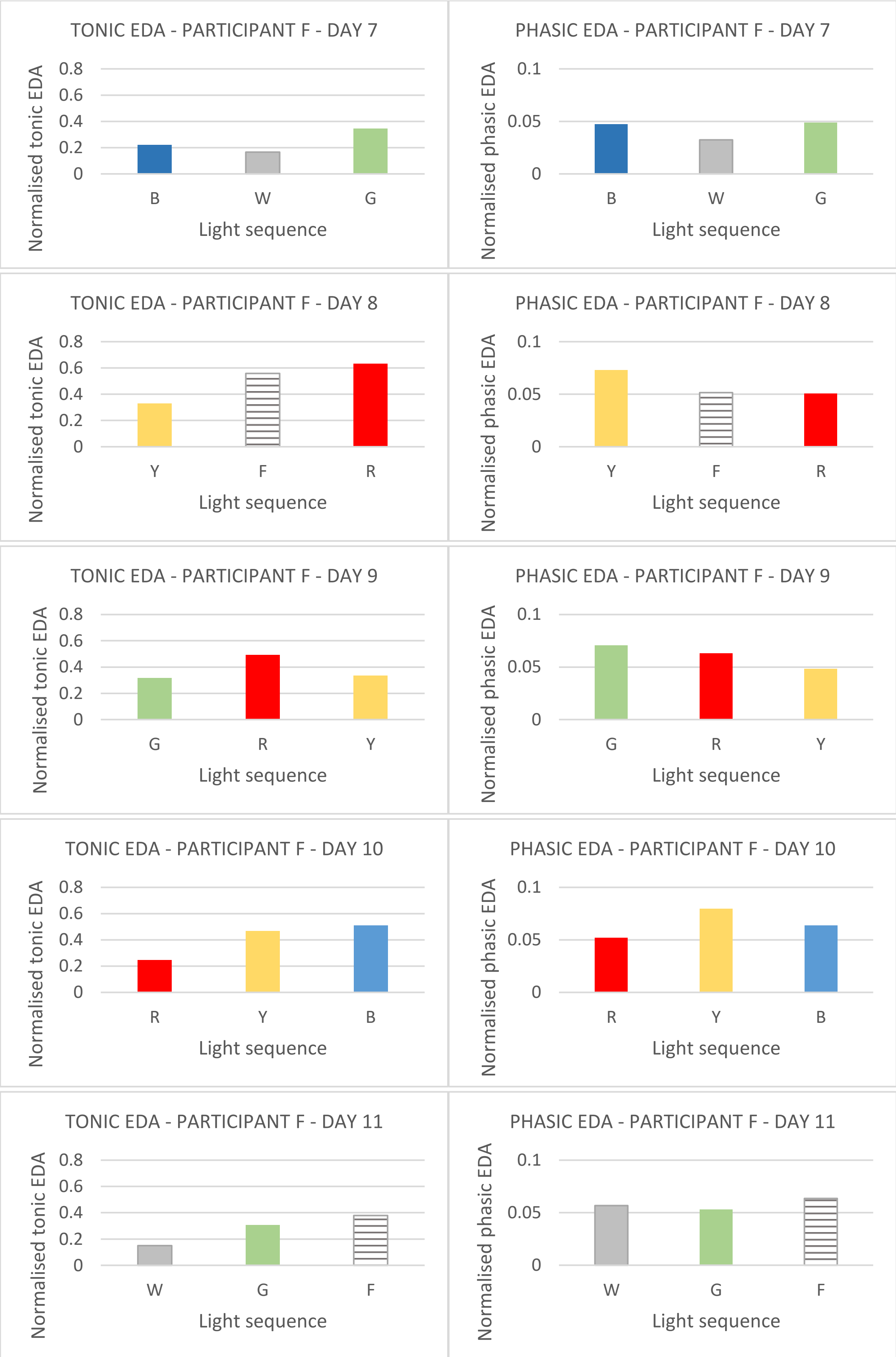











TONIC EDA - PARTICIPANT F - DAY 7
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
B
W
G
Light sequence
PHASIC EDA - PARTICIPANT F - DAY 7
Normalised phasic EDA
0.1
0.05
0
B
W
G
Light sequence
TONIC EDA - PARTICIPANT F - DAY 8
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
Y
F
R
Light sequence
PHASIC EDA - PARTICIPANT F - DAY 8
Normalised phasic EDA
0.1
0.05
0
Y
F
R
Light sequence
TONIC EDA - PARTICIPANT F - DAY 9
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
G
R
Y
Light sequence
PHASIC EDA - PARTICIPANT F - DAY 9
Normalised phasic EDA
0.1
0.05
0
G
R
Y
Light sequence
TONIC EDA - PARTICIPANT F - DAY 10
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
R
Y
B
Light sequence
PHASIC EDA - PARTICIPANT F - DAY 10
Normalised phasic EDA
0.1
0.05
0
R
Y
B
Light sequence
TONIC EDA - PARTICIPANT F - DAY 11
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
W
G
F
Light sequence
PHASIC EDA - PARTICIPANT F - DAY 11
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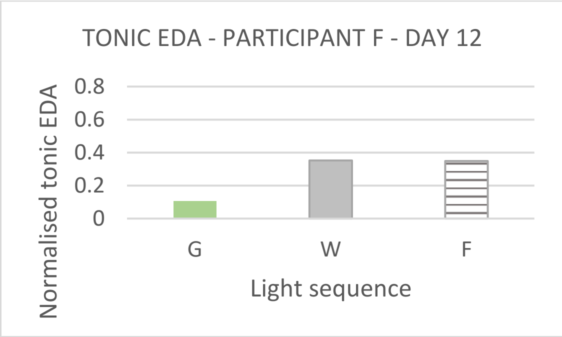
0.05
0
W
G
F
Light sequence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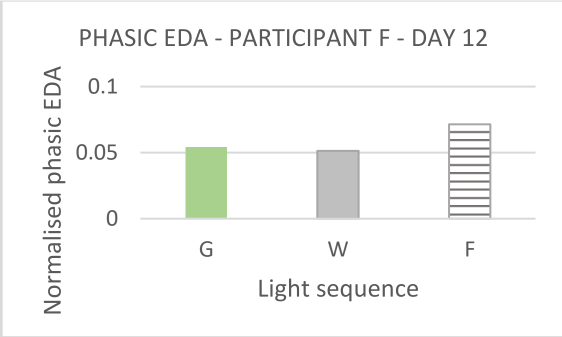
0
G
W
F
Light sequence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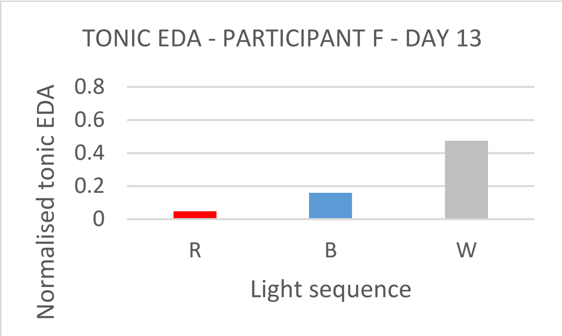
0
G
W
F
Light sequence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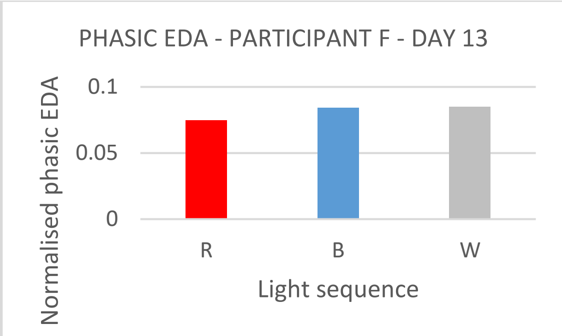
0.4
0.2
0
R
B
W
Light sequence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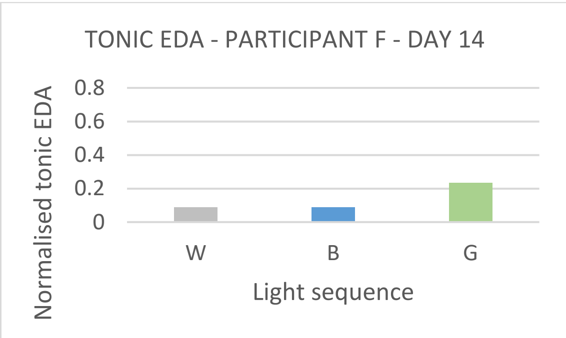
0
R
B
W
Light sequence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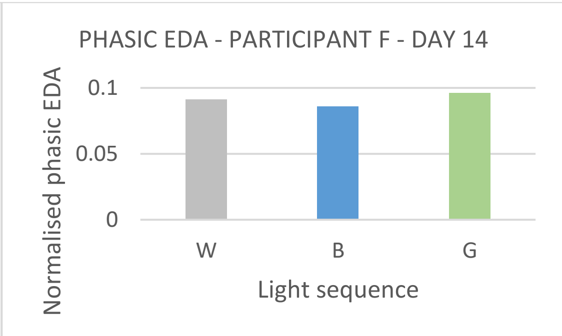
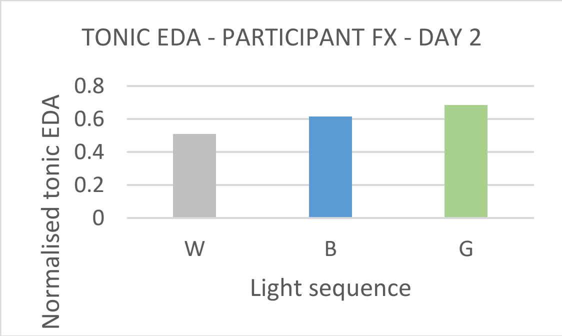
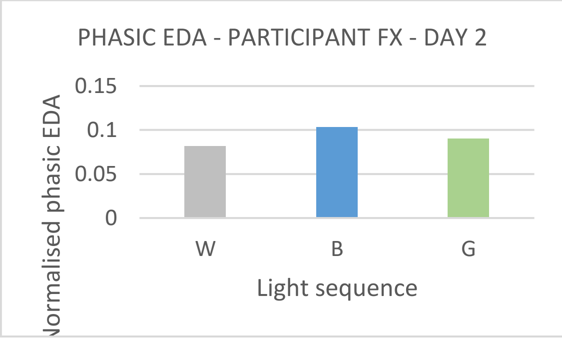
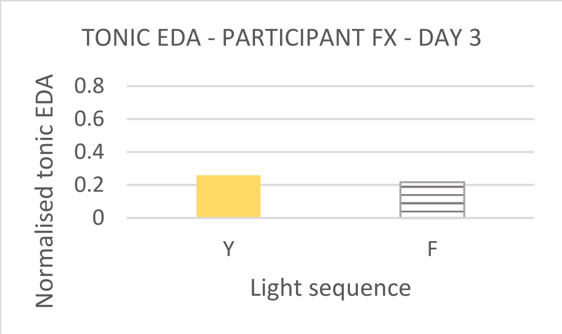
0.6
0.4
0.2
0
W
B
G
Light sequence

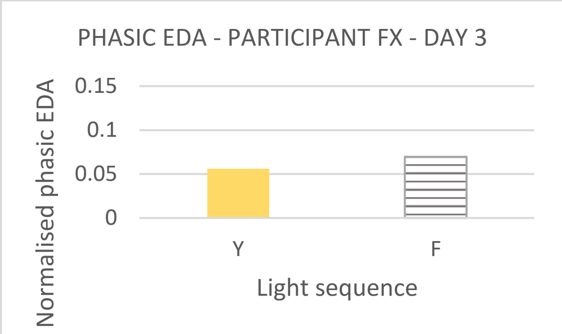

PHASIC EDA - PARTICIPANT F - DAY 14
Normalised phasic EDA
0.1
0.05
0
W
B
G
Light sequence

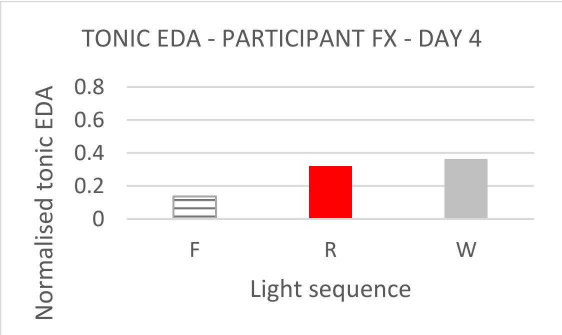
Daily data of Electrodermal Activity (Tonic and Phasic EDA) of Participant FX

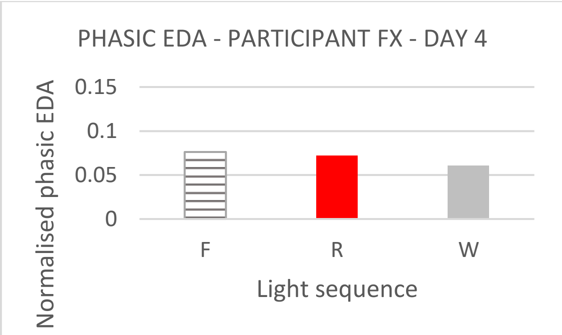


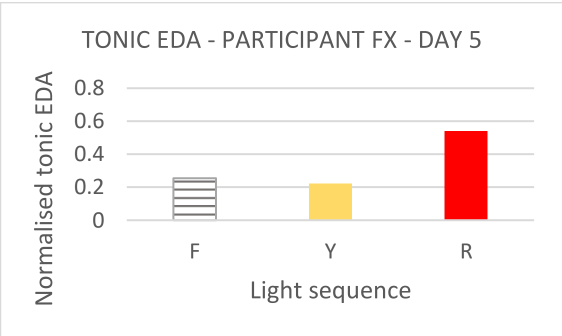


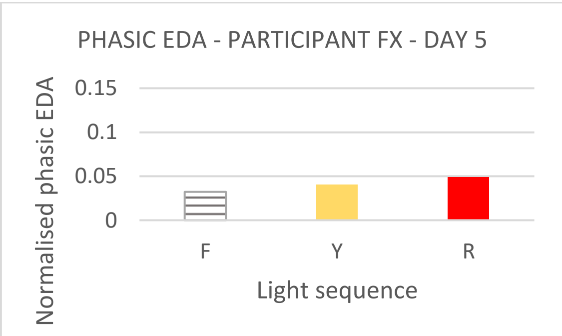


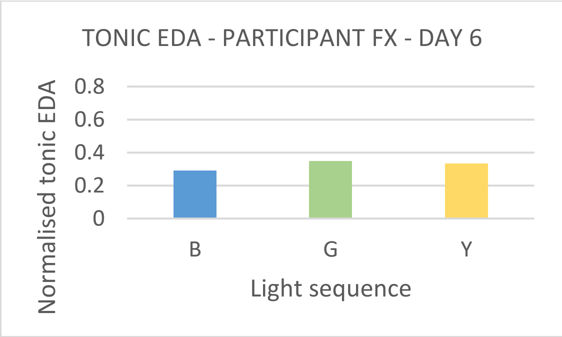








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Normalised tonic EDA
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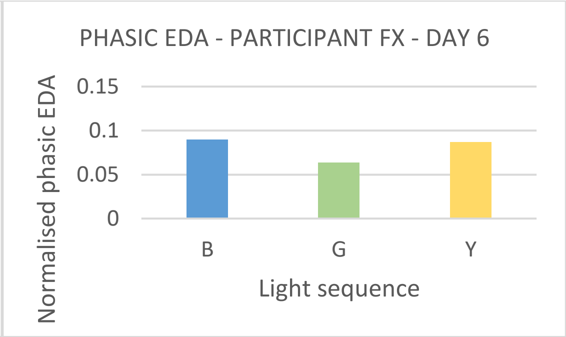
0.6
0.4
0.2
0
B
G
Y
Light sequence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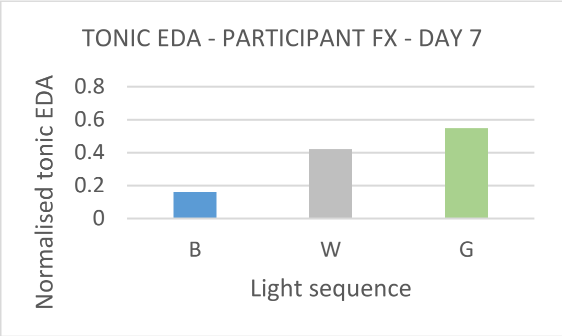
0
B
G
Y
Light sequence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Normalised tonic EDA
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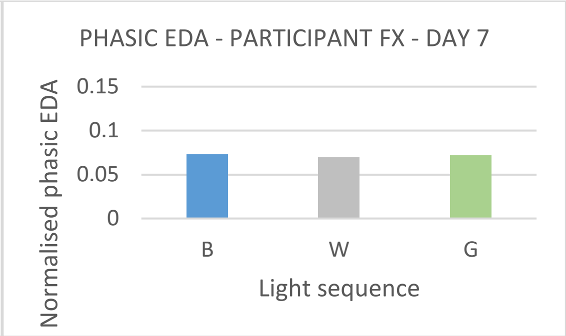
0.6
0.4
0.2
0
B
W
G
Light sequence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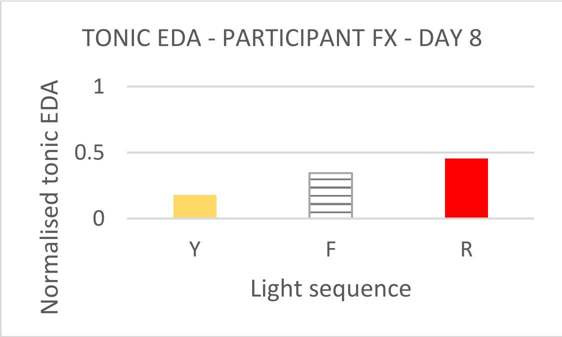
0
B
W
G
Light sequence


TONIC EDA - PARTICIPANT FX - DAY 8
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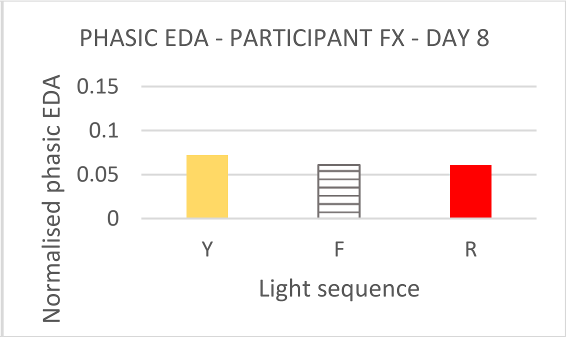
0.5
0
Y
F
R
Light sequence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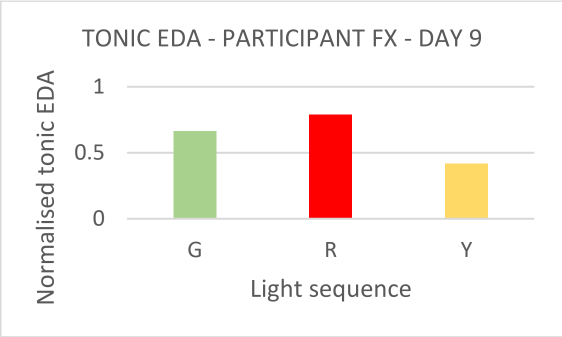
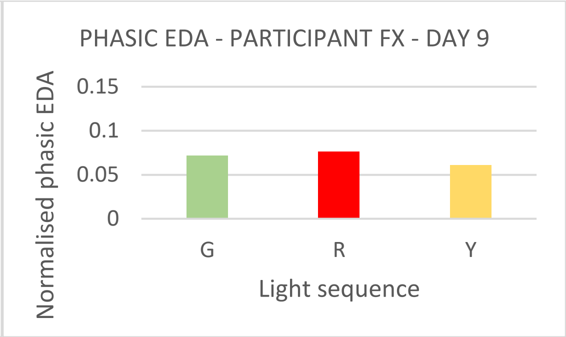
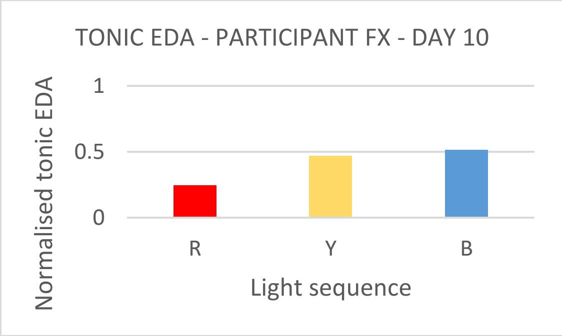
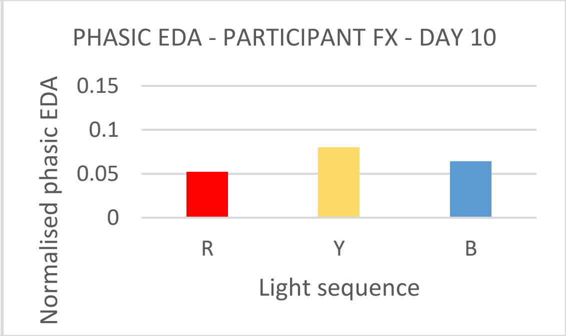
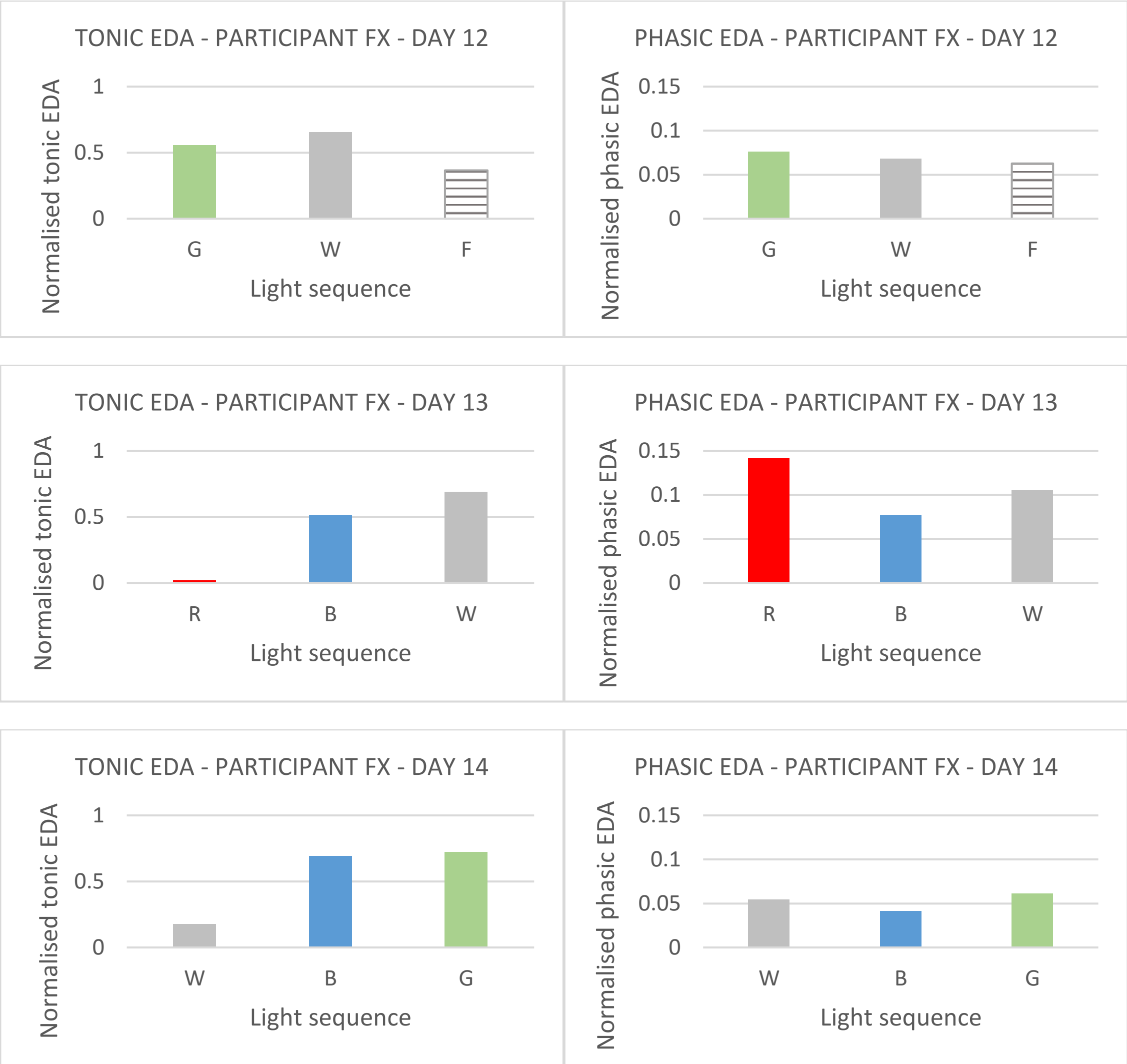
0.05
0
Y
F
R
Light sequence


TONIC EDA - PARTICIPANT FX - DAY 9
Normalised tonic EDA
1
0.5
0
G
R
Y
Light sequence

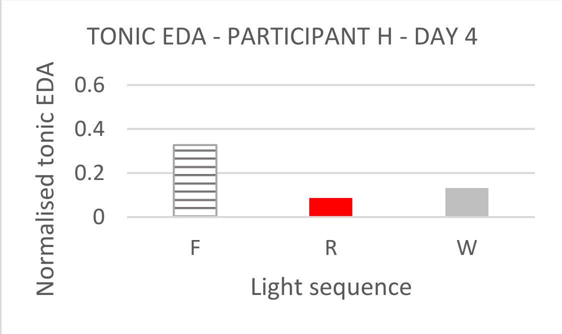

PHASIC EDA - PARTICIPANT FX - DAY 9
Normalised phasic EDA
0.15
0.1
0.05
0
G
R
Y
Light sequence

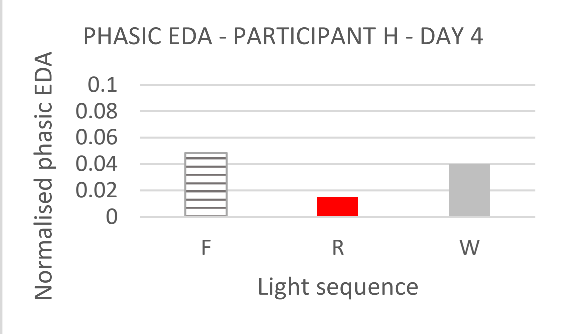

TONIC EDA - PARTICIPANT FX - DAY 10
Normalised tonic EDA
1
0.5
0
R
Y
B
Light sequence

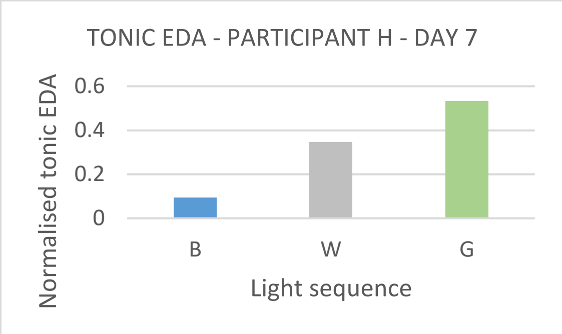

PHASIC EDA - PARTICIPANT FX - DAY 10
Normalised phasic EDA
0.15
0.1
0.05
0
R
Y
B
Light sequence

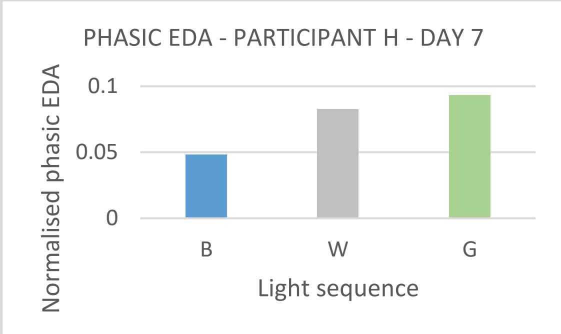

TONIC EDA - PARTICIPANT FX - DAY 12
Normalised tonic EDA
1
0.5
0
G
W
F
Light sequence
PHASIC EDA - PARTICIPANT FX - DAY 12
Normalised phasic EDA
0.15
0.1
0.05
0
G
W
F
Light sequence
TONIC EDA - PARTICIPANT FX - DAY 13
Normalised tonic EDA
1
0.5
0
R
B
W
Light sequence
PHASIC EDA - PARTICIPANT FX - DAY 13
Normalised phasic EDA
0.15
0.1
0.05
0
R
B
W
Light sequence
TONIC EDA - PARTICIPANT FX - DAY 14
Normalised tonic EDA
1
0.5
0
W
B
G
Light sequence
PHASIC EDA - PARTICIPANT FX - DAY 14
Normalised phasic EDA
0.15
0.1
0.05
0
W
B
G
Light sequence

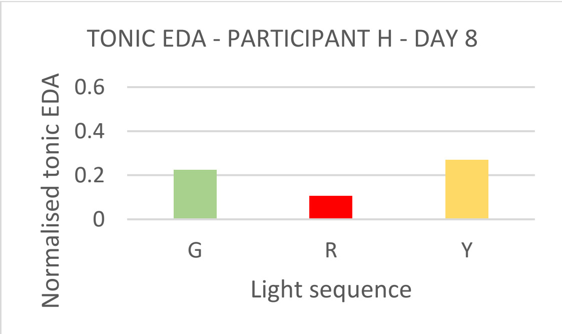
Daily data of Electrodermal Activity (Tonic and Phasic EDA) of Participant H

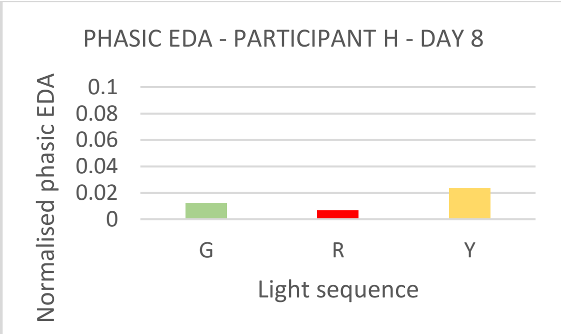


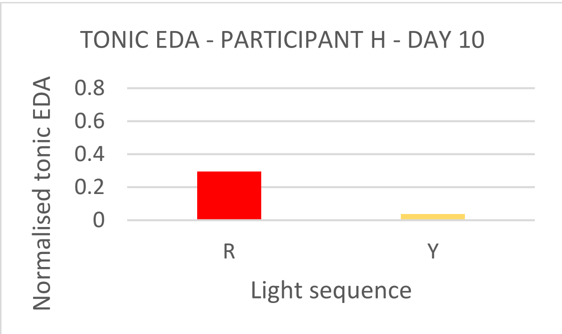


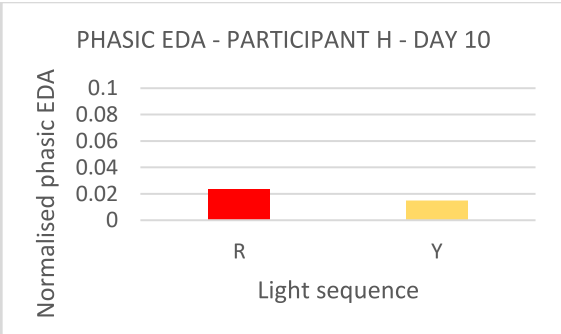


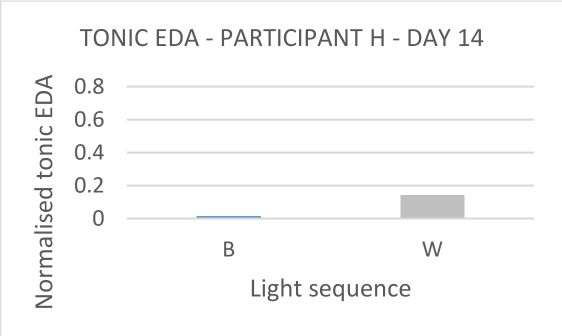


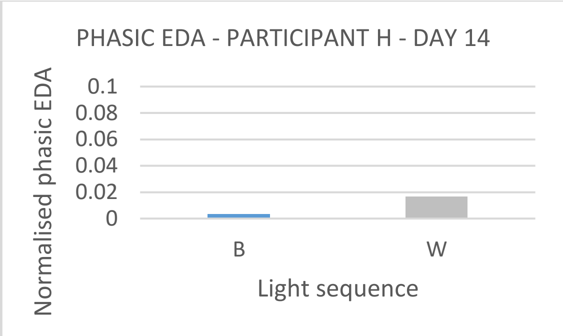




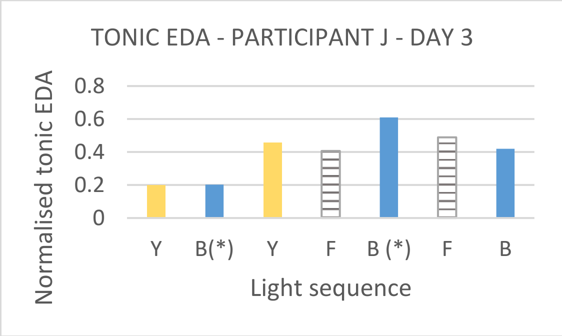


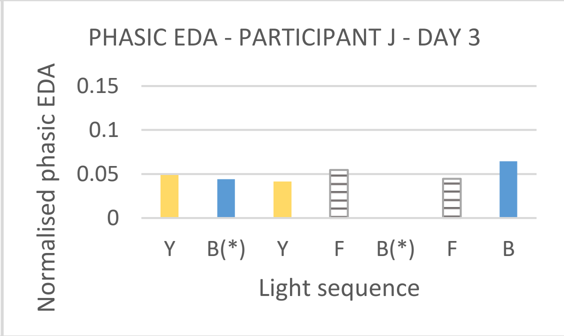


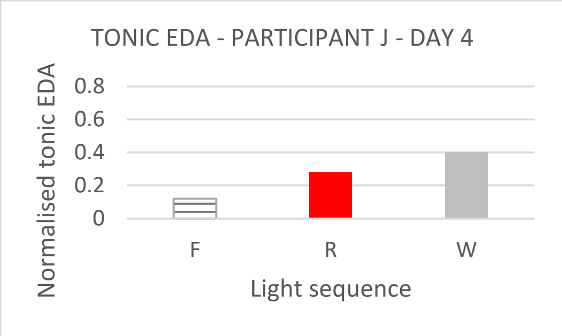

TONIC EDA - PARTICIPANT H - DAY 14
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
B
W
Light sequence

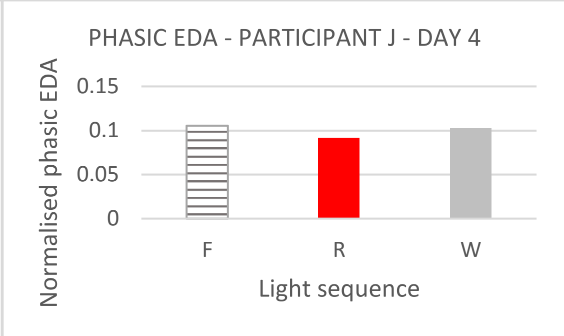

PHASIC EDA - PARTICIPANT H - DAY 14
Normalised phasic EDA
0.1
0.08
0.06
0.04
0.02
0
B
W
Light sequence

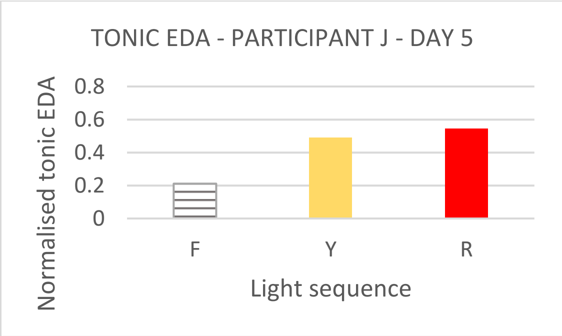
Daily data of Electrodermal Activity (Tonic and Phasic EDA) of Participant J

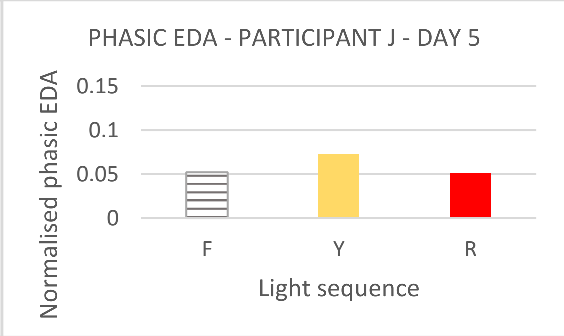


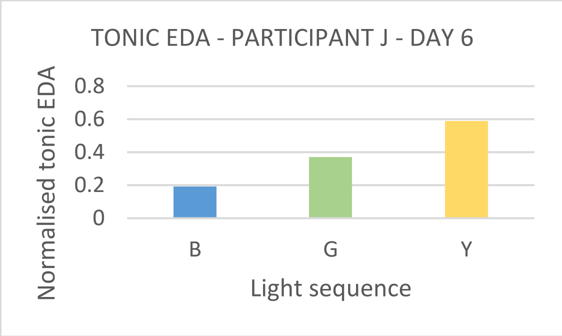


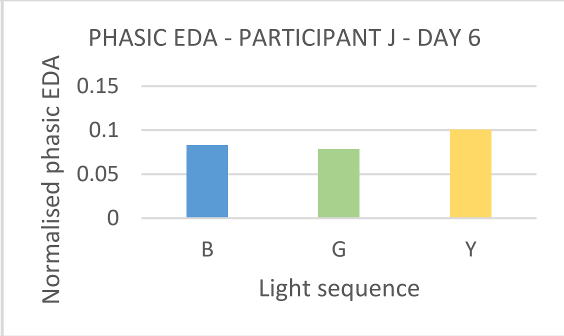


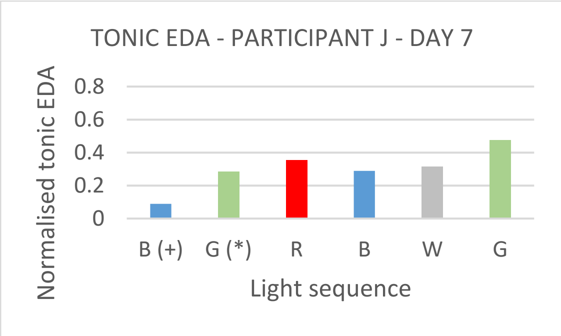


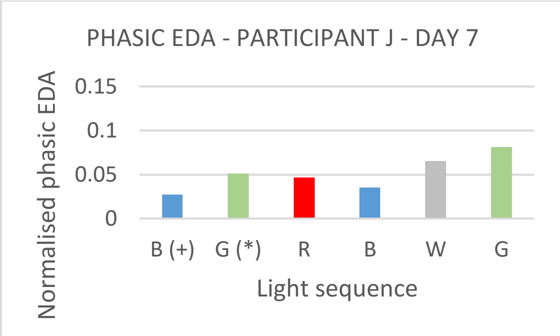


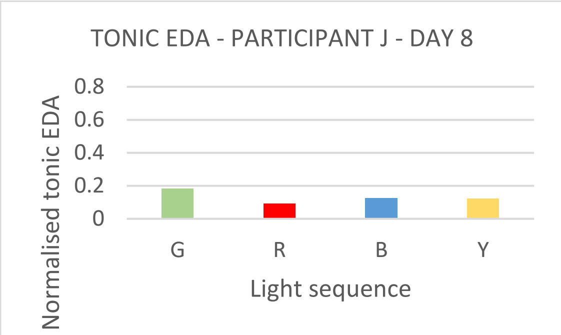


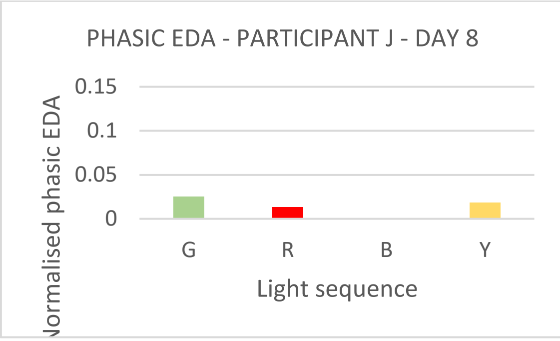


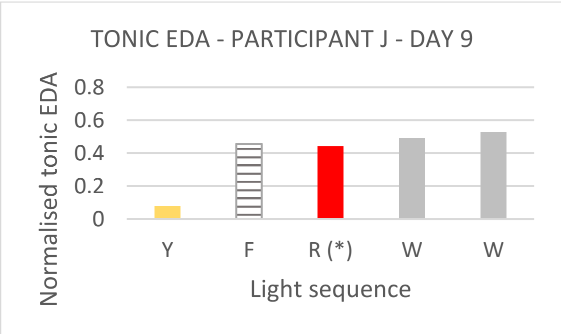


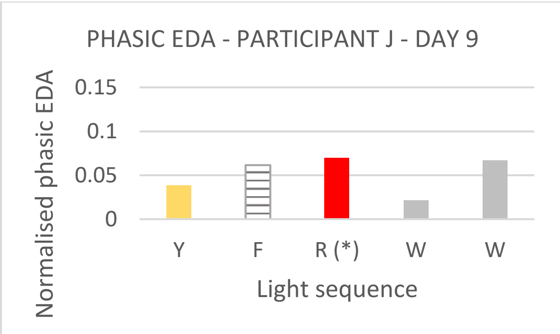

TONIC EDA - PARTICIPANT J - DAY 7
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
B (+) G (*) R B W G
Light sequence

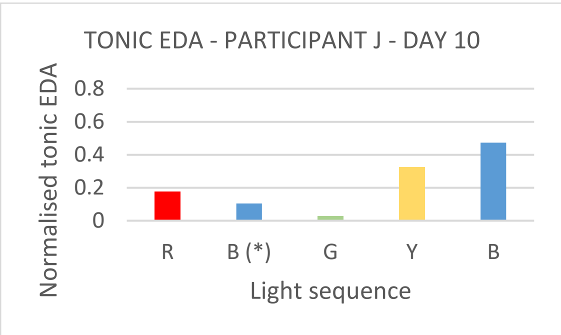

PHASIC EDA - PARTICIPANT J - DAY 7
Normalised phasic EDA
0.15
0.1
0.05
0
B (+) G (*) R B W G
Light sequence

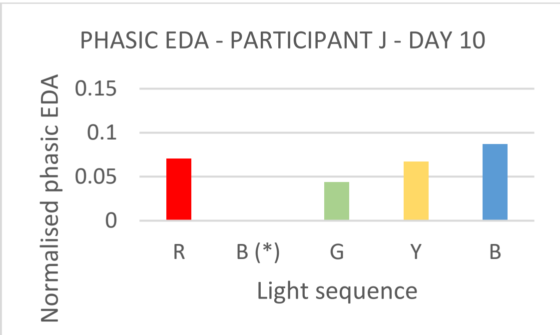

TONIC EDA - PARTICIPANT J - DAY 8
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
G R B Y
Light sequence

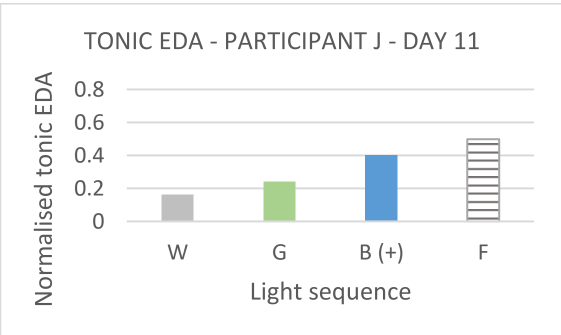

PHASIC EDA - PARTICIPANT J - DAY 8
Normalised phasic EDA
0.15
0.1
0.05
0
G R B Y
Light sequence

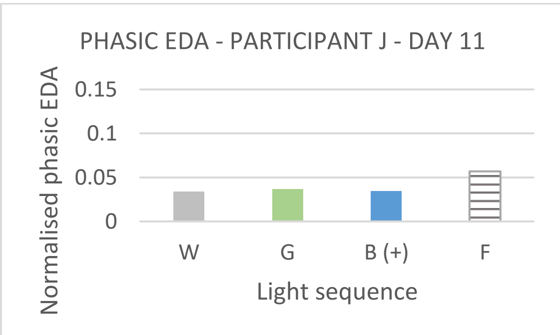

TONIC EDA - PARTICIPANT J - DAY 9
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
Y F R (*) W W
Light sequence

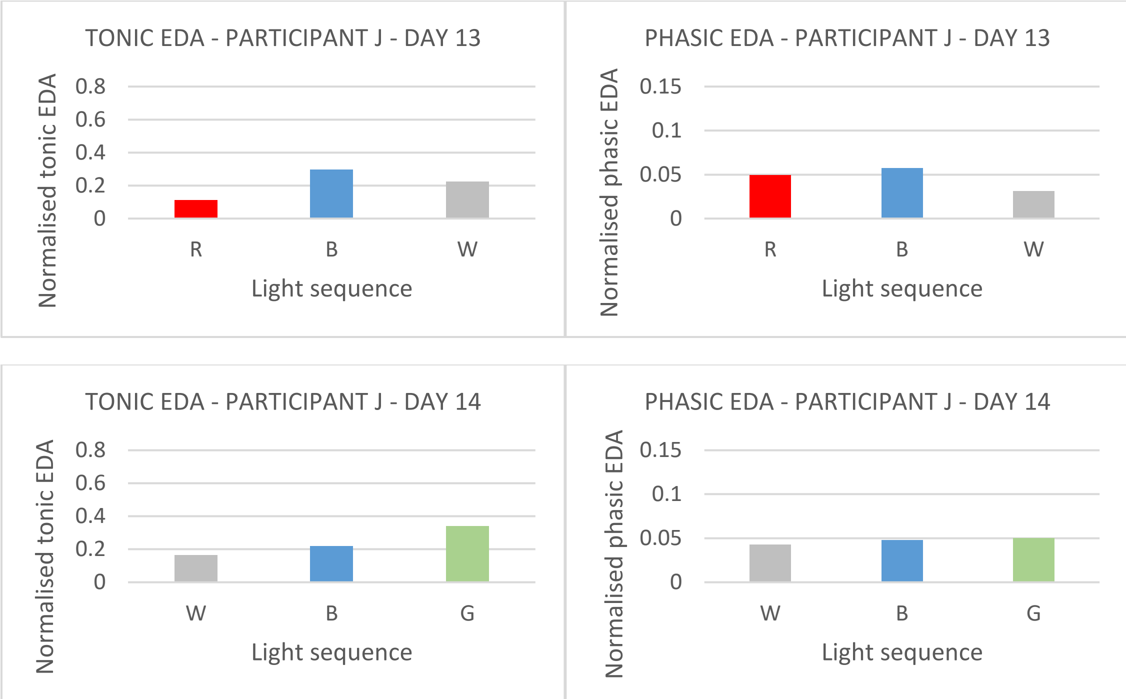

PHASIC EDA - PARTICIPANT J - DAY 9
Normalised phasic EDA
0.15
0.1
0.05
0
Y F R (*) W W
Light sequence


TONIC EDA - PARTICIPANT J - DAY 10
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
R B (*) G Y B
Light sequence


PHASIC EDA - PARTICIPANT J - DAY 10
Normalised phasic EDA
0.15
0.1
0.05
0
R B (*) G Y B
Light sequence

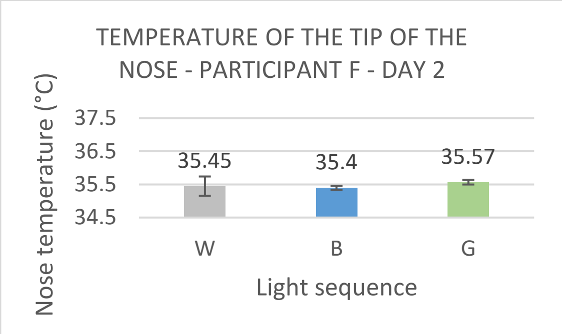

TONIC EDA - PARTICIPANT J - DAY 11
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
W G B (+) F
Light sequence

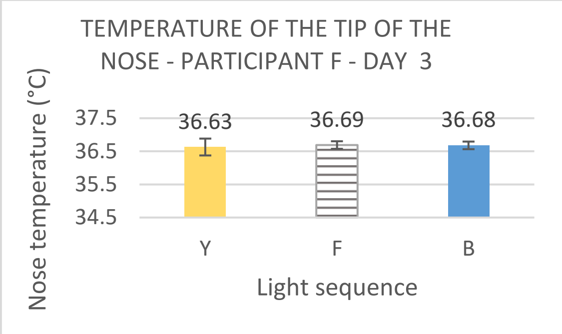

PHASIC EDA - PARTICIPANT J - DAY 11
Normalised phasic EDA
0.15
0.1
0.05
0
W G B (+) F
Light sequence

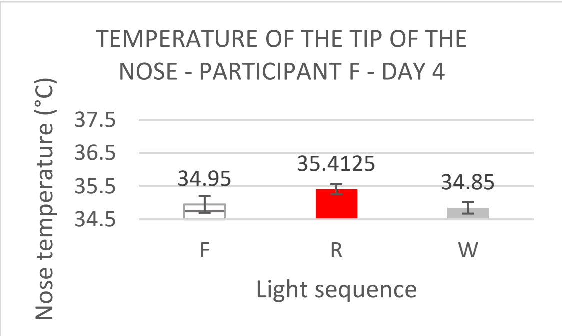

TONIC EDA - PARTICIPANT J - DAY 13
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
R
B
W
Light sequence
PHASIC EDA - PARTICIPANT J - DAY 13
Normalised phasic EDA
0.15
0.1
0.05
0
R
B
W
Light sequence
TONIC EDA - PARTICIPANT J - DAY 14
Normalised tonic EDA
0.8
0.6
0.4
0.2
0
W
B
G
Light sequence
PHASIC EDA - PARTICIPANT J - DAY 14
Normalised phasic EDA
0.15
0.1
0.05
0
W
B
G
Light sequence

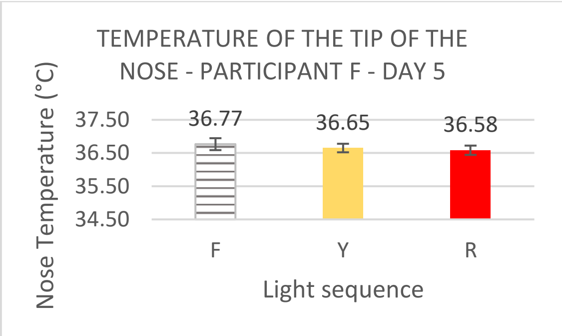
APPENDIX G. RESULTS – DAILY ANALYSIS THERMOGRAPHY

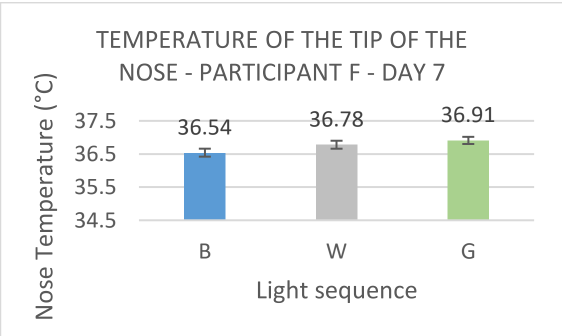
Daily data of Thermography (Temperature of the tip of the nose) of Participant F:

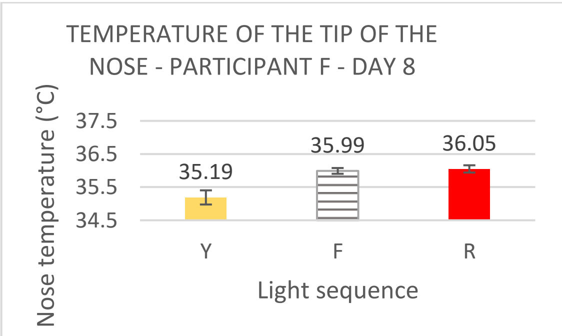


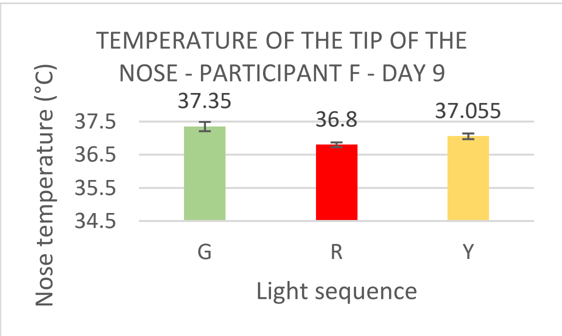


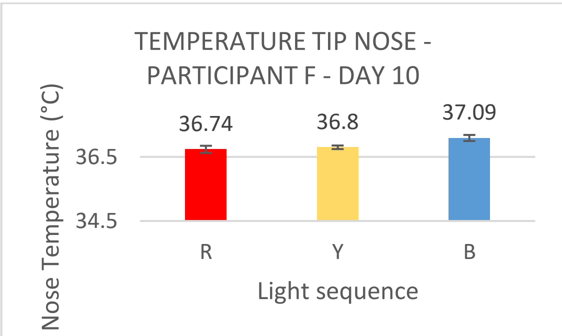


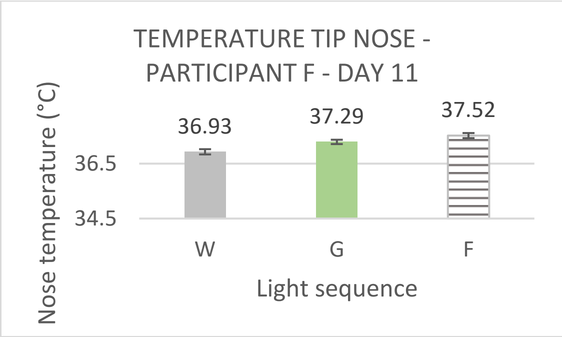


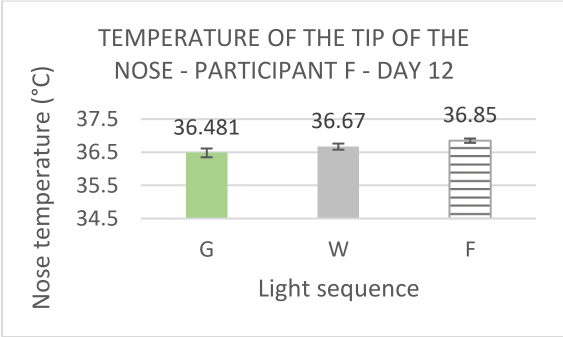


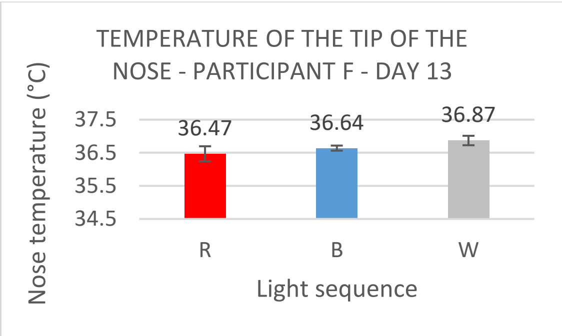


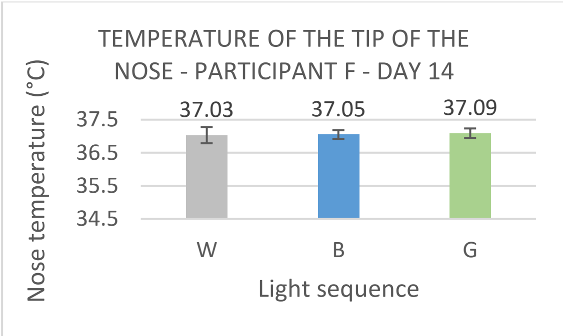




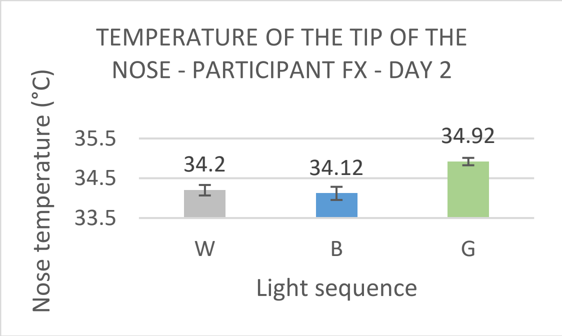

TEMPERATURE TIP NOSE - PARTICIPANT F - DAY 11
Nose temperature (°C)
36.5
34.5
36.93
37.29
37.52
W
G
F
Light sequence

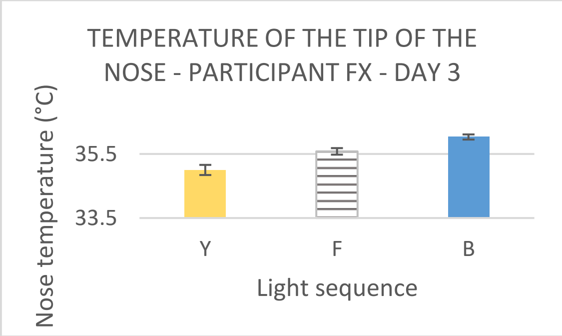

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT F - DAY 12
Nose temperature (°C)
37.5
36.5
35.5
34.5
36.481
36.67
36.85
G
W
F
Light sequence

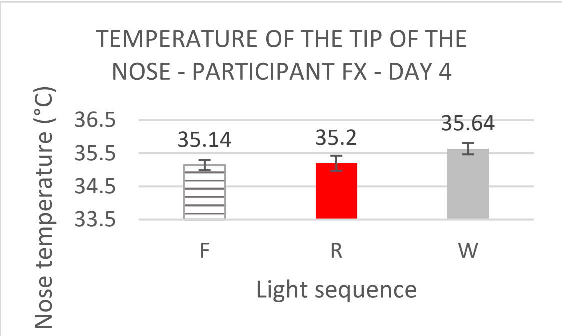

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT F - DAY 13
Nose temperature (°C)
37.5
36.5
35.5
34.5
36.47
36.64
36.87
R
B
W
Light sequence

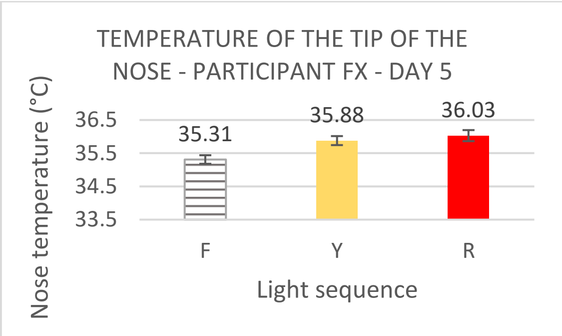

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT F - DAY 14
Nose temperature (°C)
37.5
36.5
35.5
34.5
37.03
37.05
37.09
W
B
G
Light sequence

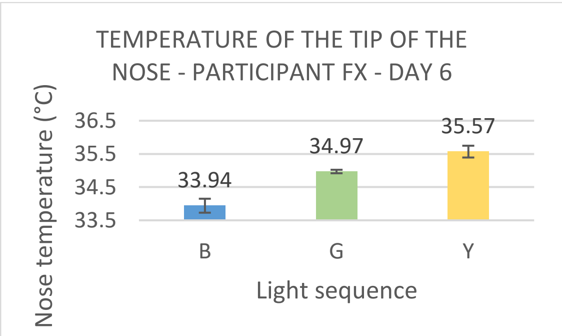
Daily data of Thermography (Temperature of the tip of the nose) of Participant FX

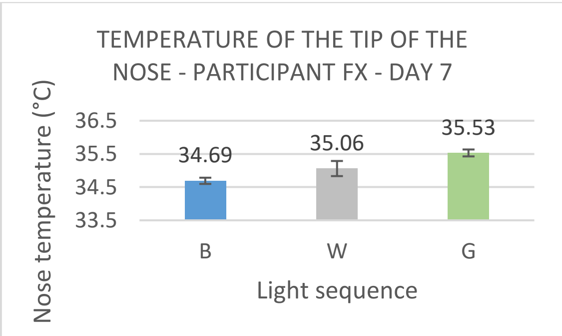


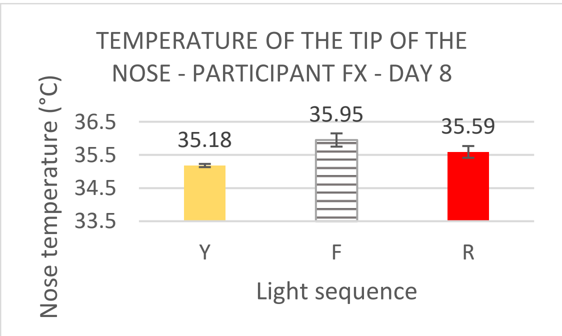


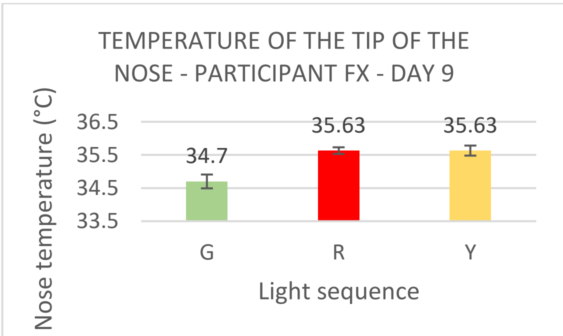


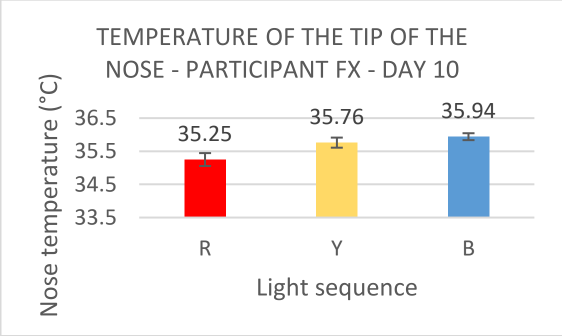


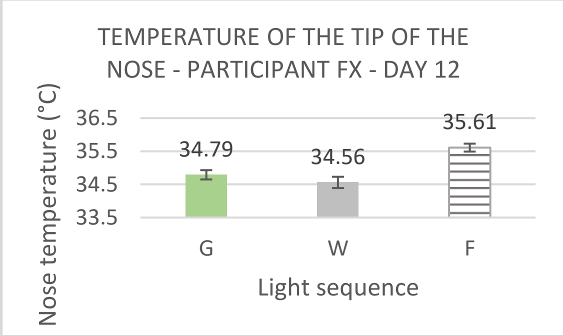


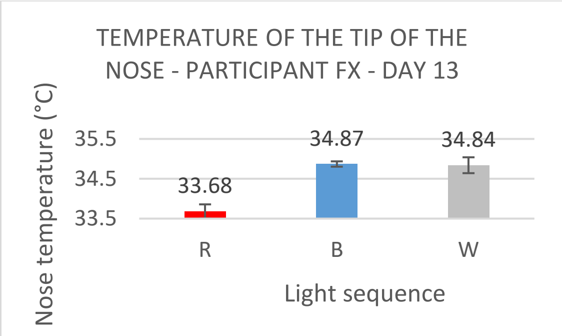


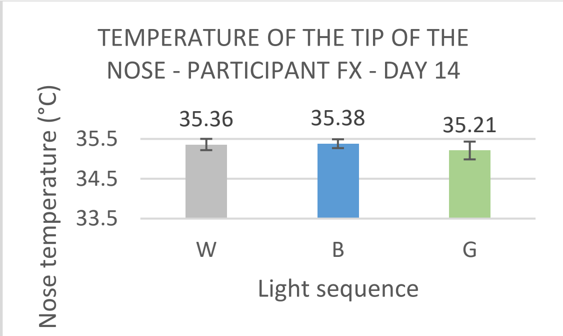




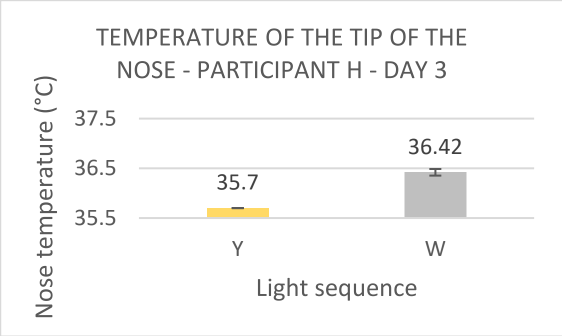

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT FX - DAY 10
Nose temperature (°C)
36.5
35.5
34.5
33.5
35.25
35.76
35.94
R
Y
B
Light sequence

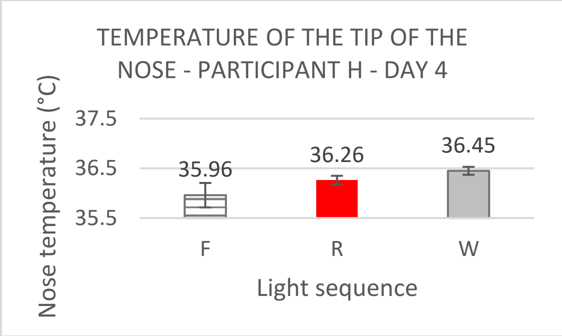

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT FX - DAY 12
Nose temperature (°C)
36.5
35.5
34.5
33.5
34.79
34.56
35.61
G
W
F
Light sequence

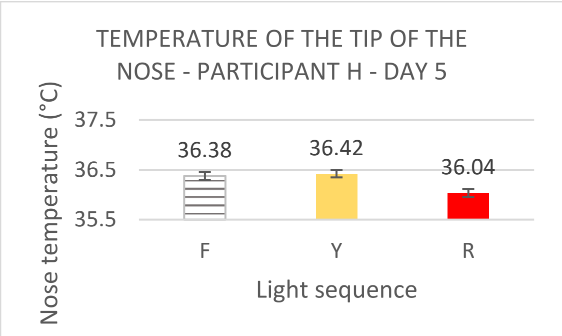

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT FX - DAY 13
Nose temperature (°C)
35.5
34.5
33.5
33.68
34.87
34.84
R
B
W
Light sequence

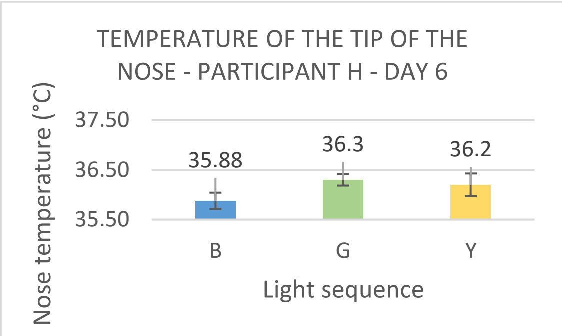

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT FX - DAY 14
Nose temperature (°C)
35.5
34.5
33.5
35.36
35.38
35.21
W
B
G
Light sequence

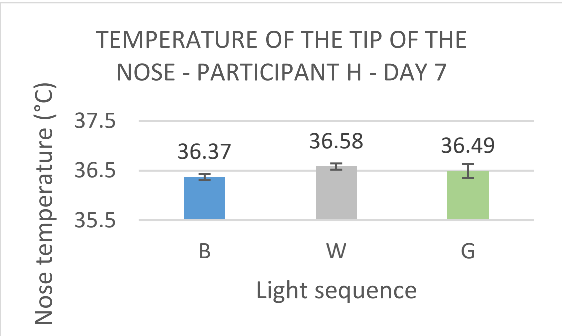
Daily data of Thermography (Temperature of the tip of the nose) of Participant H

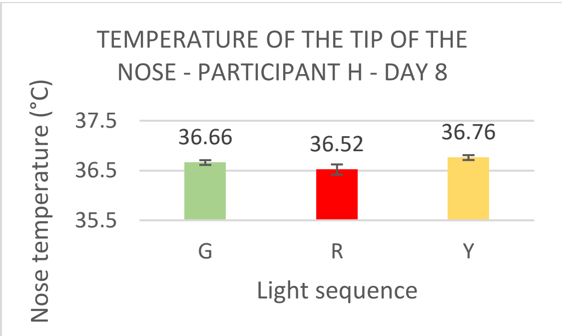


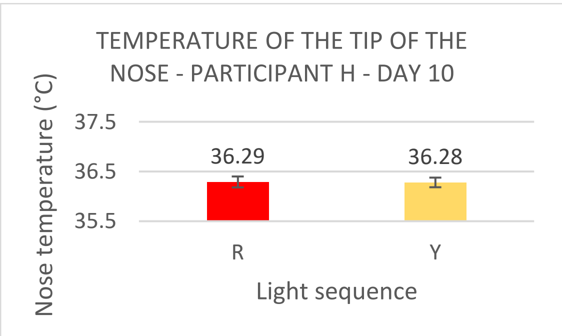


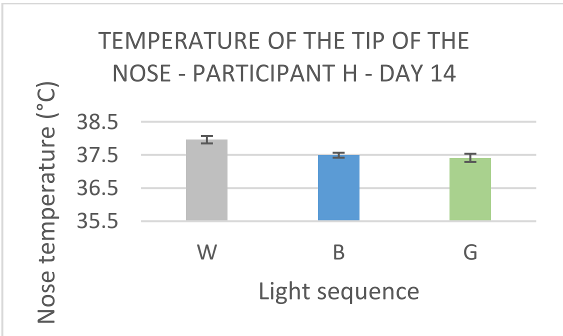




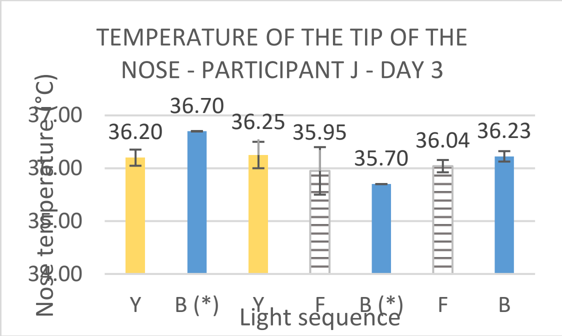


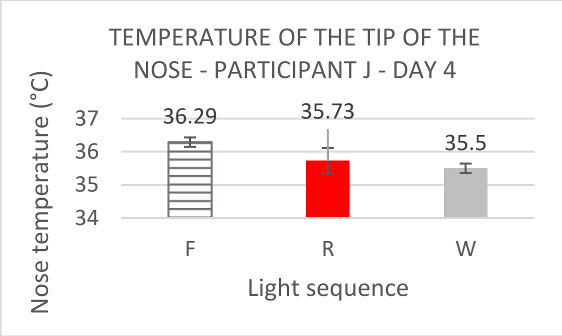


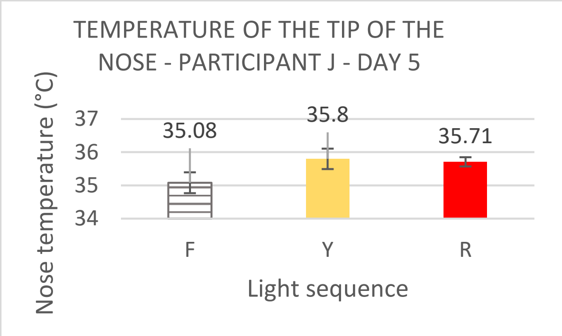


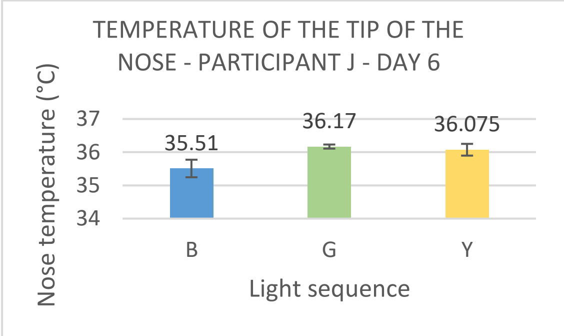


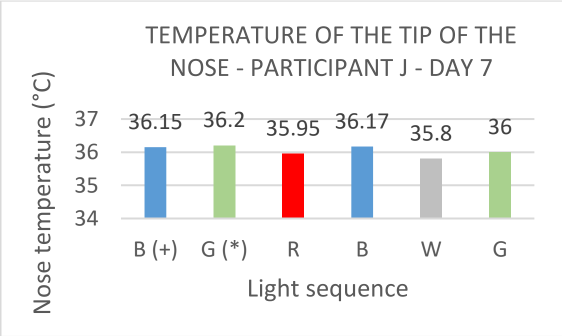
Daily data of Thermography (Temperature of the tip of the nose) of Participant J

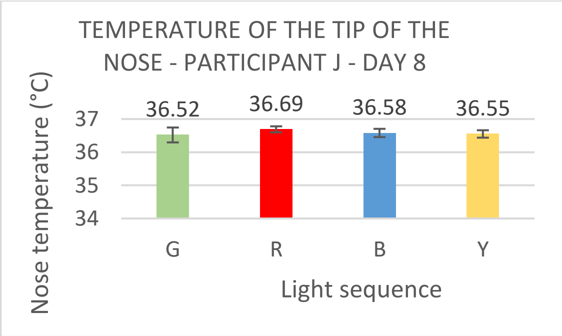


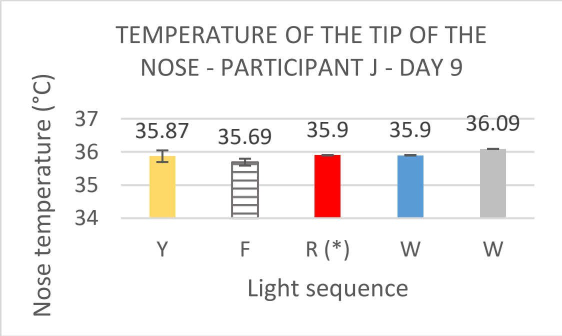


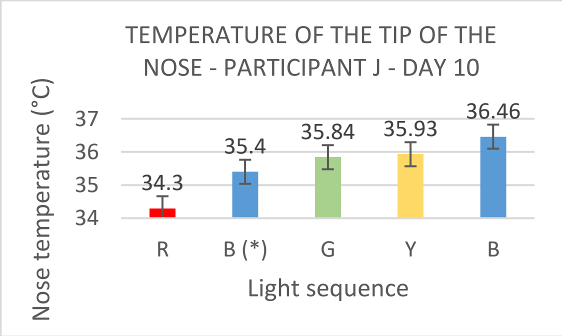


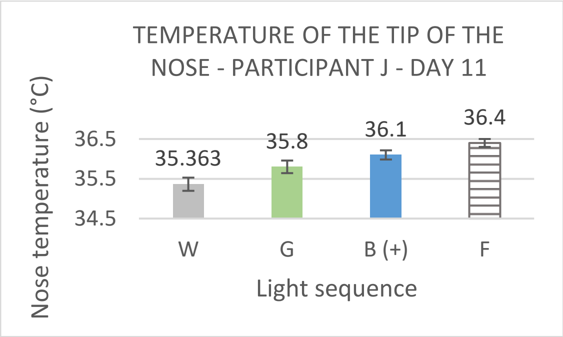


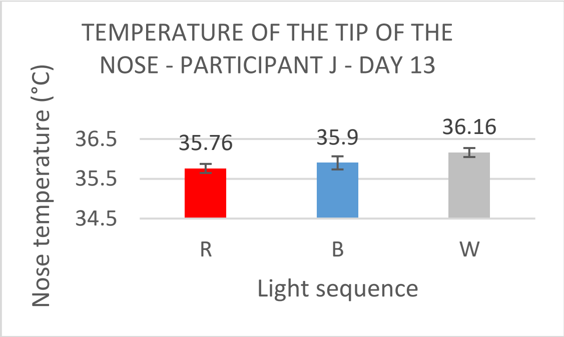


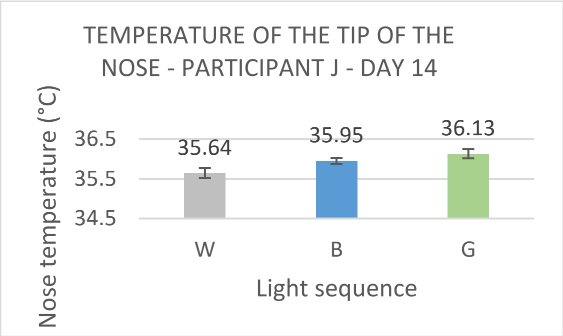






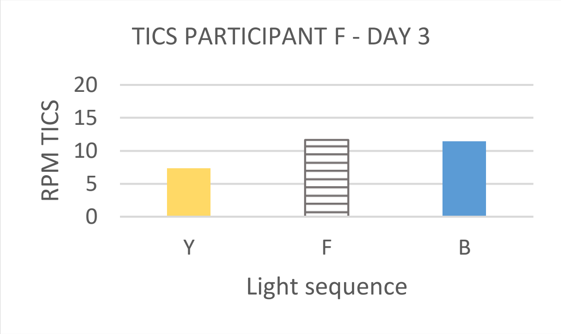

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT J - DAY 11
Nose temperature (°C)
36.5
35.5
34.5
35.363
35.8
36.1
36.4
W
G
B (+)
F
Light sequence

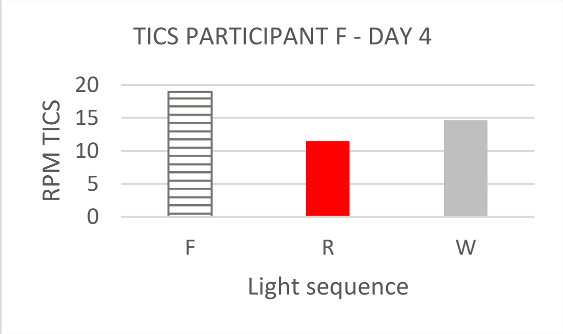

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT J - DAY 13
Nose temperature (°C)
36.5
35.5
34.5
35.76
35.9
36.16
R
B
W
Light sequence

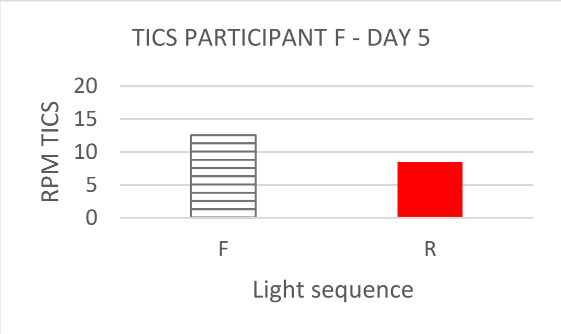

TEMPERATURE OF THE TIP OF THE NOSE - PARTICIPANT J - DAY 14
Nose temperature (°C)
36.5
35.5
34.5
35.64
35.95
36.13
W
B
G
Light sequence

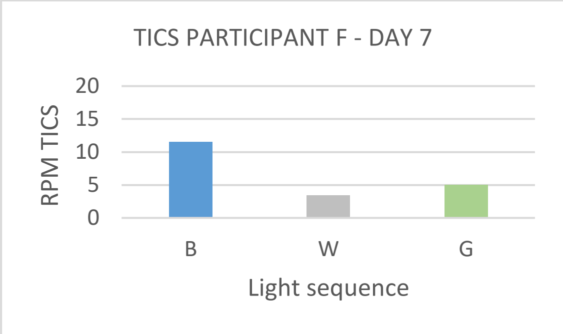
APPENDIX H. RESULTS – DAILY ANALYSIS RPM OF TICS

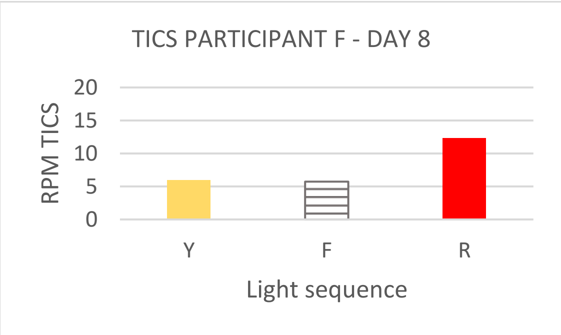
Daily data of the rate per minute of repetitive behaviour (RPM tics) of Participant F:

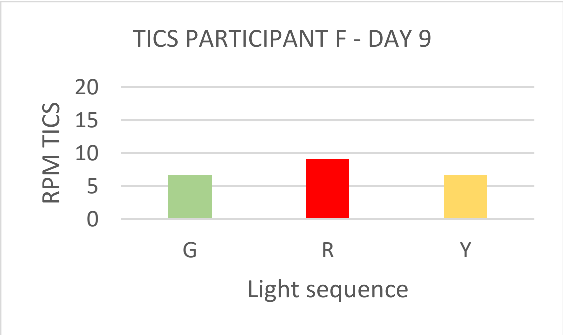


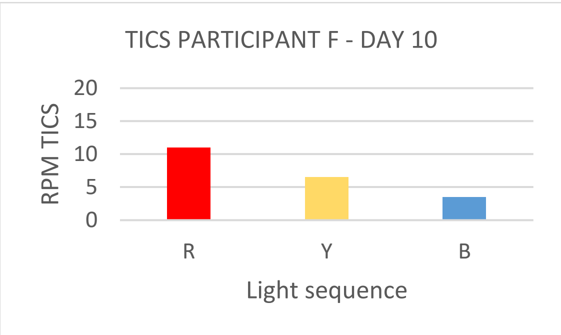


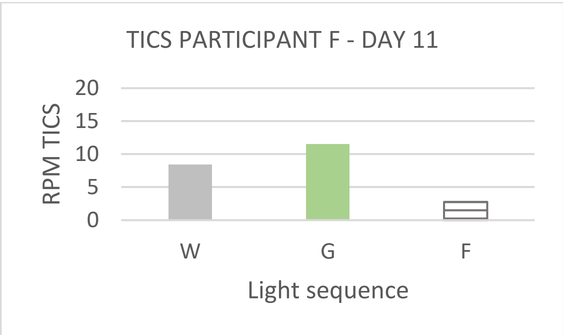


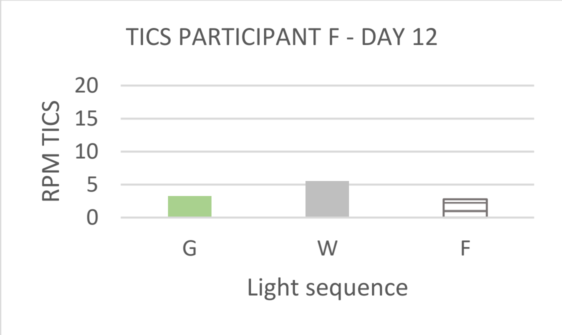


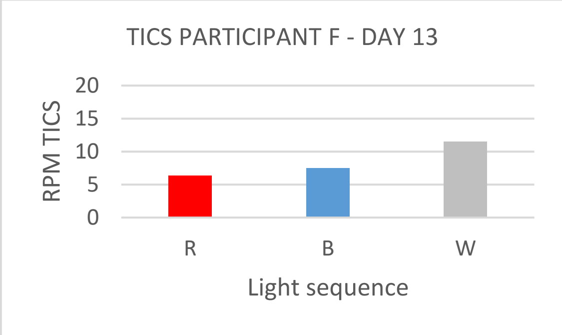


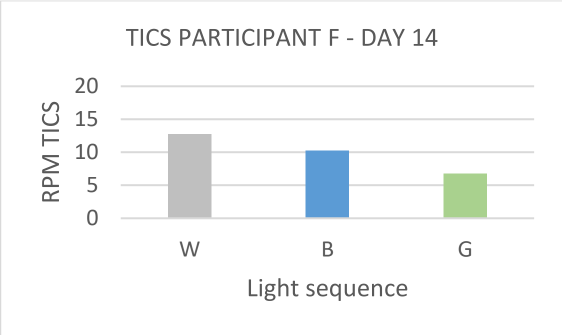




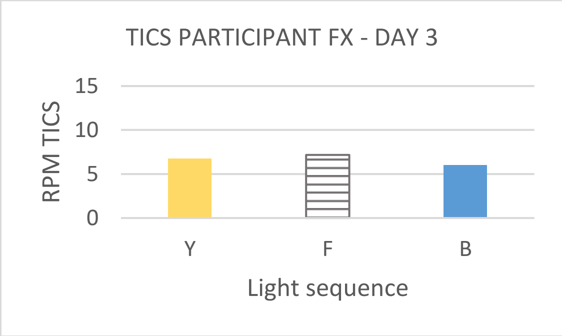


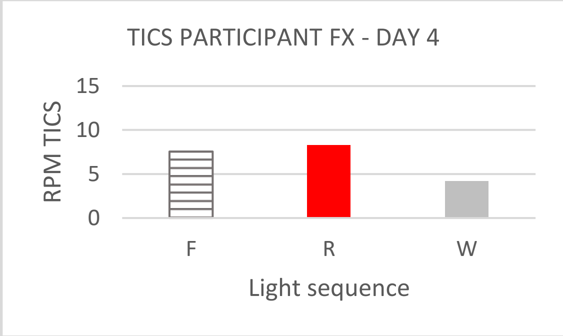

TICS PARTICIPANT F - DAY 12
RPM TICS
20
15
10
5
0
G
W
F
Light sequence

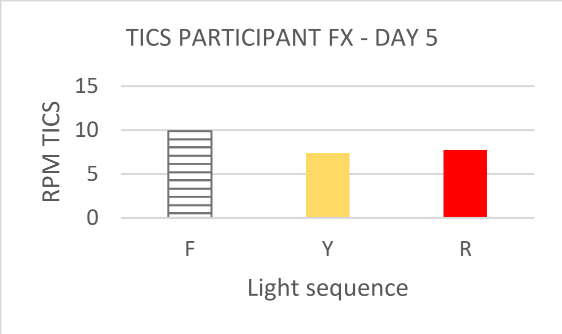

TICS PARTICIPANT F - DAY 13
RPM TICS
20
15
10
5
0
R
B
W
Light sequence

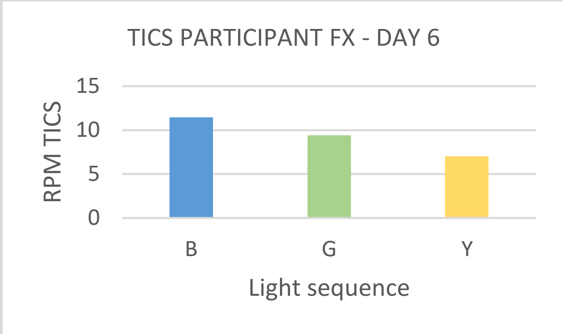

TICS PARTICIPANT F - DAY 14
RPM TICS
20
15
10
5
0
W
B
G
Light sequence

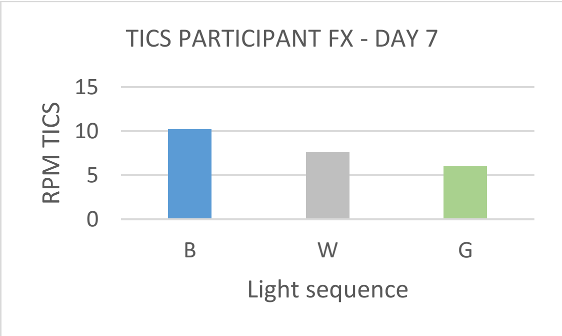
Daily data of the rate per minute of repetitive behaviour (RPM tics) of Participant FX

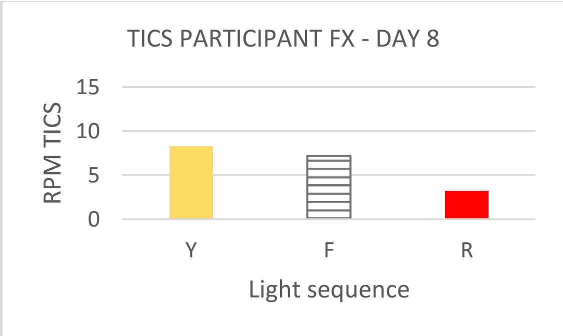


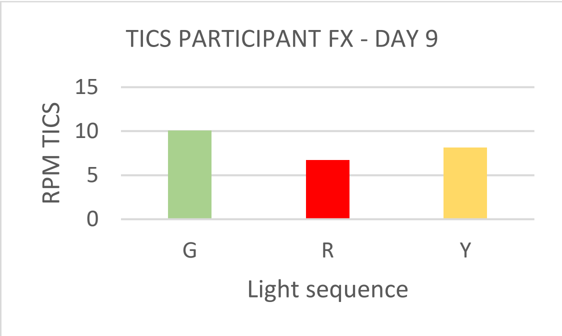


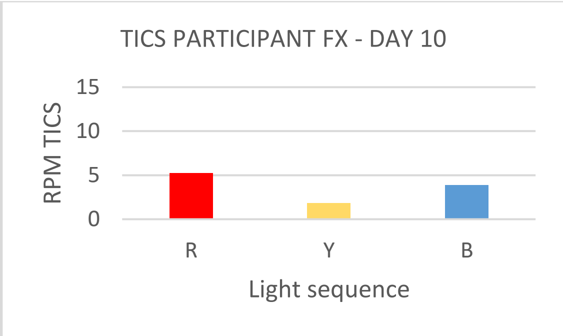


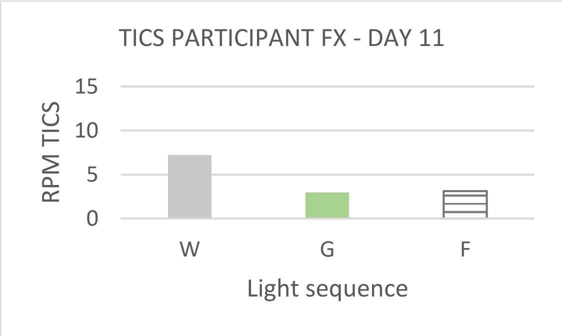


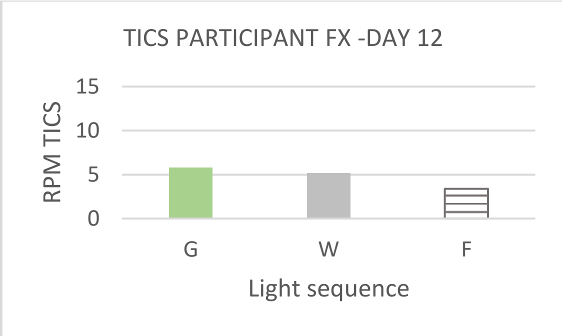


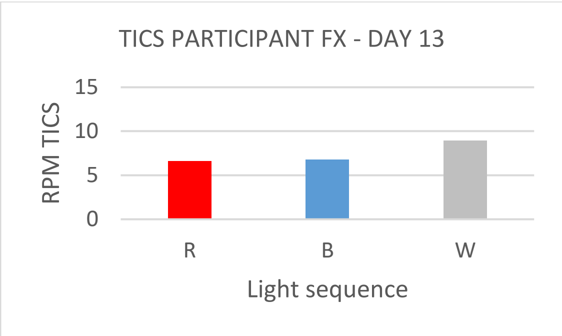


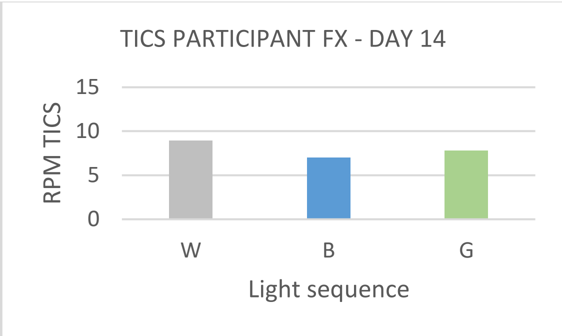




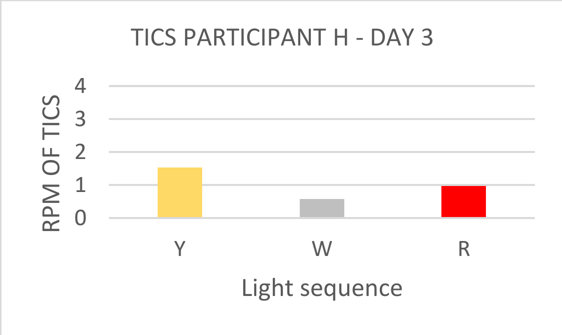

TICS PARTICIPANT FX - DAY 11
RPM TICS
15
10
5
0
W
G
F
Light sequence

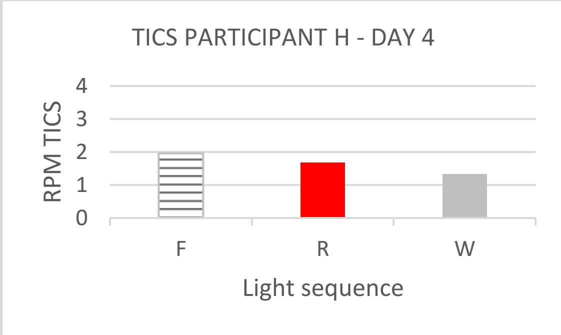

TICS PARTICIPANT FX -DAY 12
RPM TICS
15
10
5
0
G
W
F
Light sequence

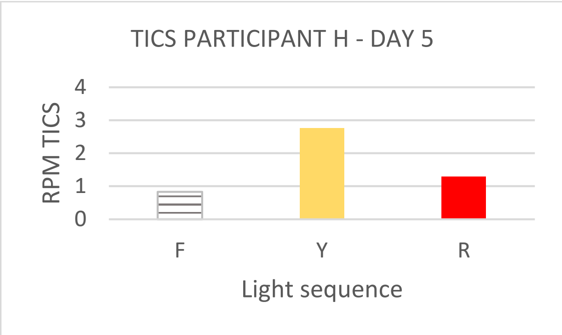

TICS PARTICIPANT FX - DAY 13
RPM TICS
15
10
5
0
R
B
W
Light sequence

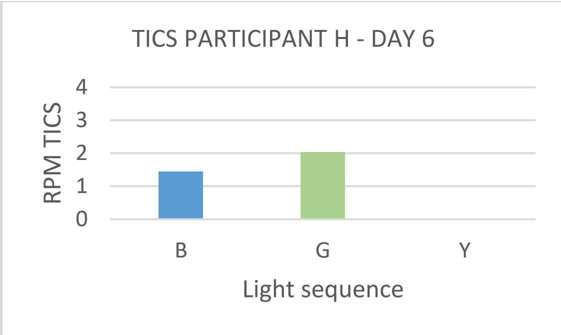

TICS PARTICIPANT FX - DAY 14
RPM TICS
15
10
5
0
W
B
G
Light sequence

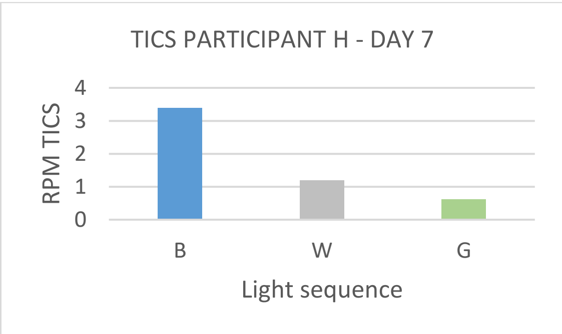
Daily data of the rate per minute of repetitive behaviour (RPM tics) of Participant H

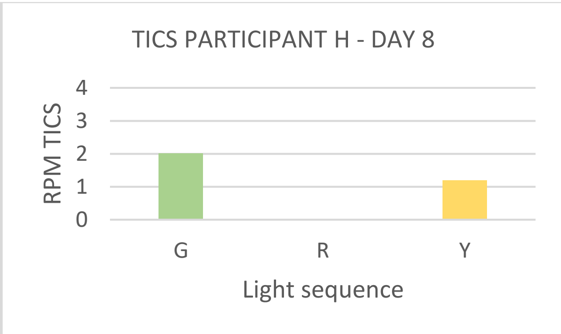


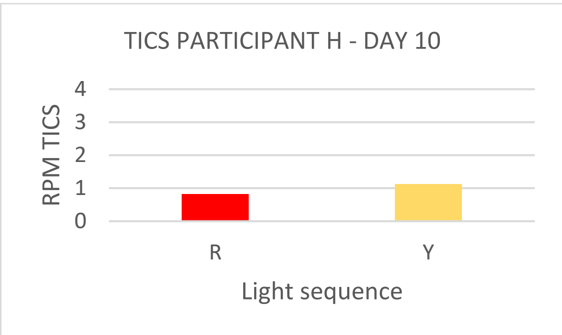


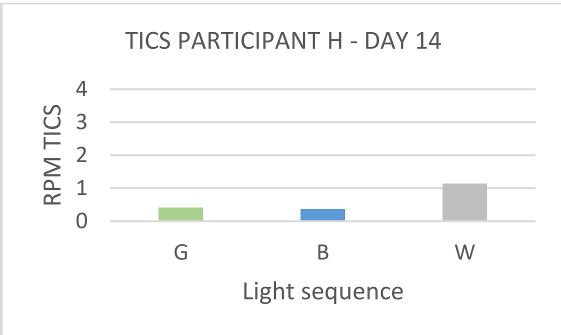




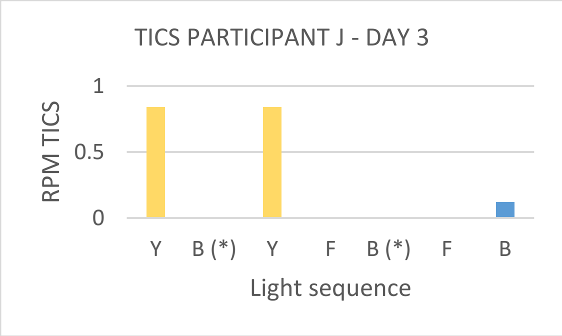


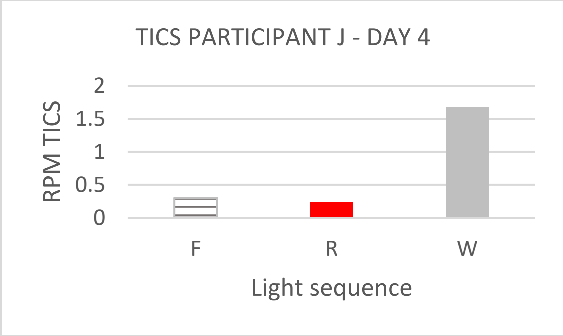


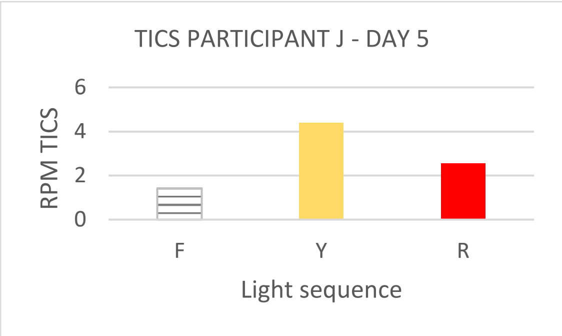


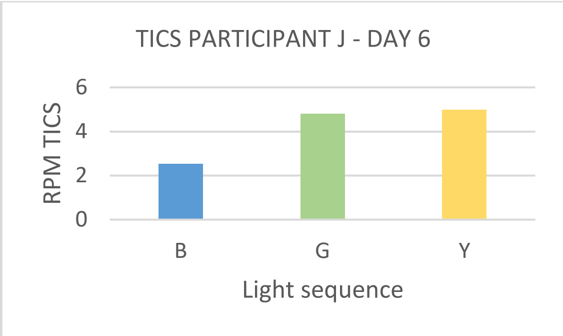


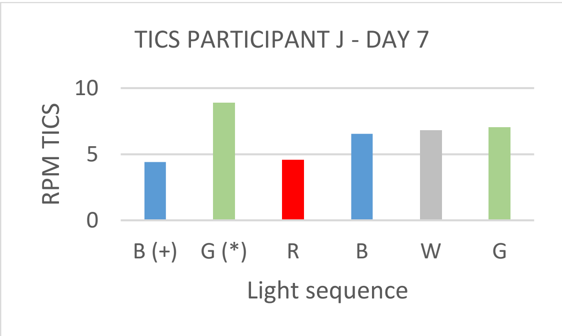
Daily data of the rate per minute of repetitive behaviour (RPM tics) of Participant J

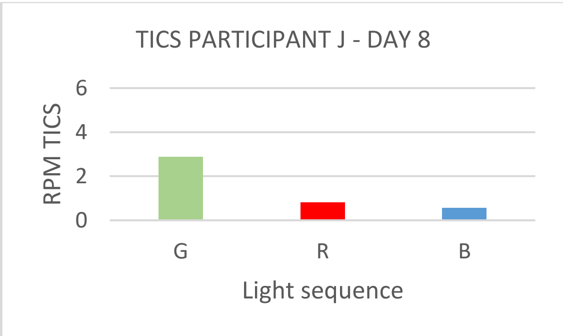


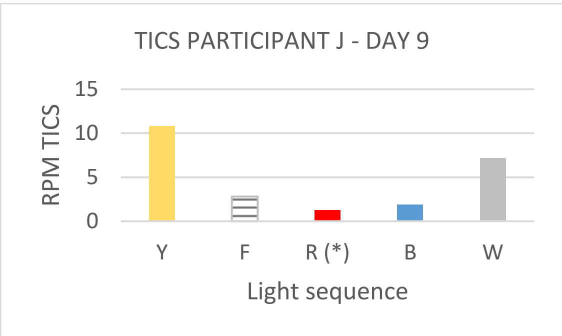


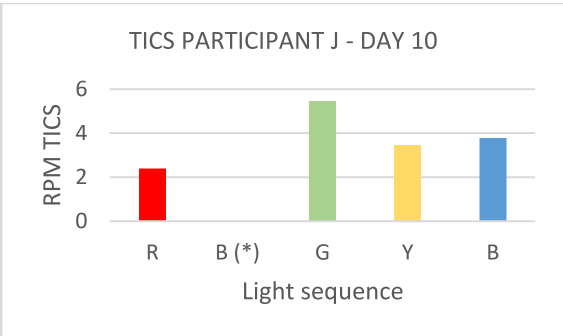


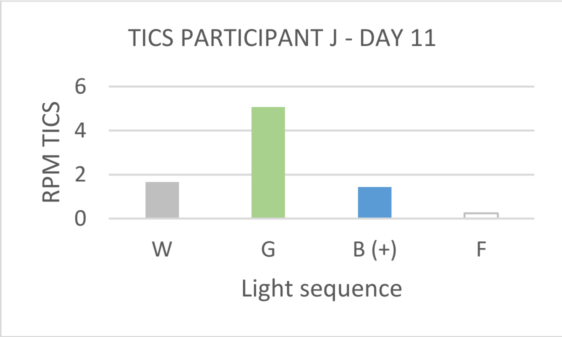


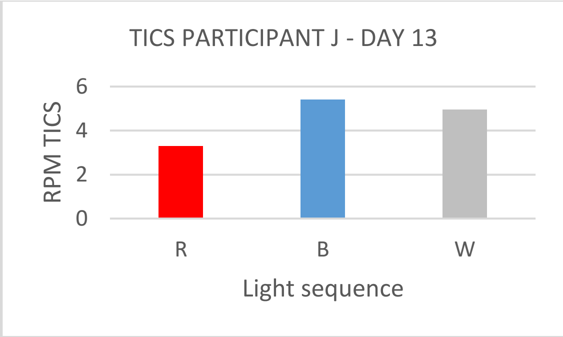


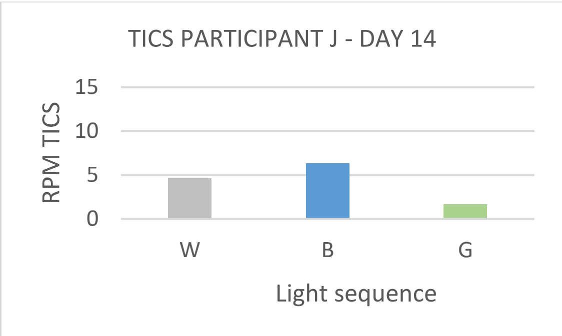






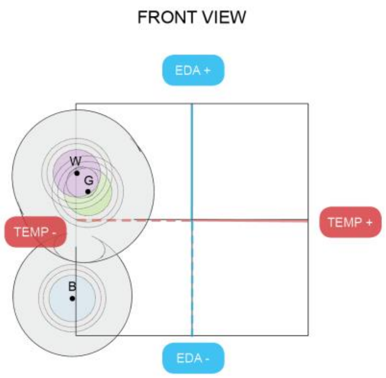

TICS PARTICIPANT J - DAY 11
RPM TICS
6
4
2
0
W
G
B (+)
F
Light sequence

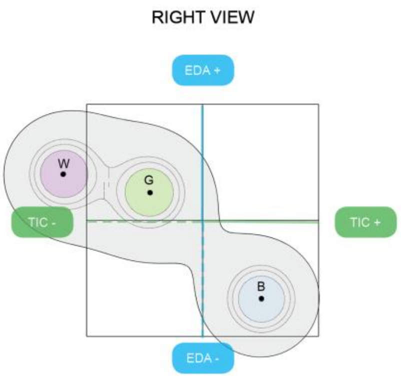

TICS PARTICIPANT J - DAY 13
RPM TICS
6
4
2
0
R
B
W
Light sequence

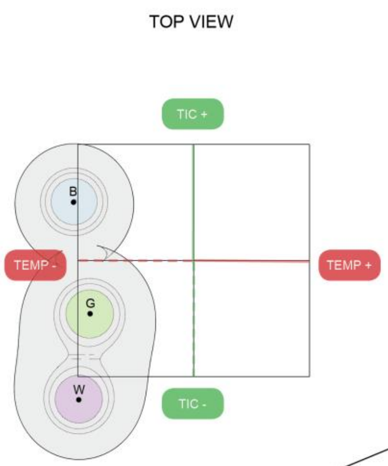

TICS PARTICIPANT J - DAY 14
RPM TICS
15
10
5
0
W
B
G
Light sequence

APPENDIX I. RESULTS – 3D MOOD BOX DAILY ANALYSIS

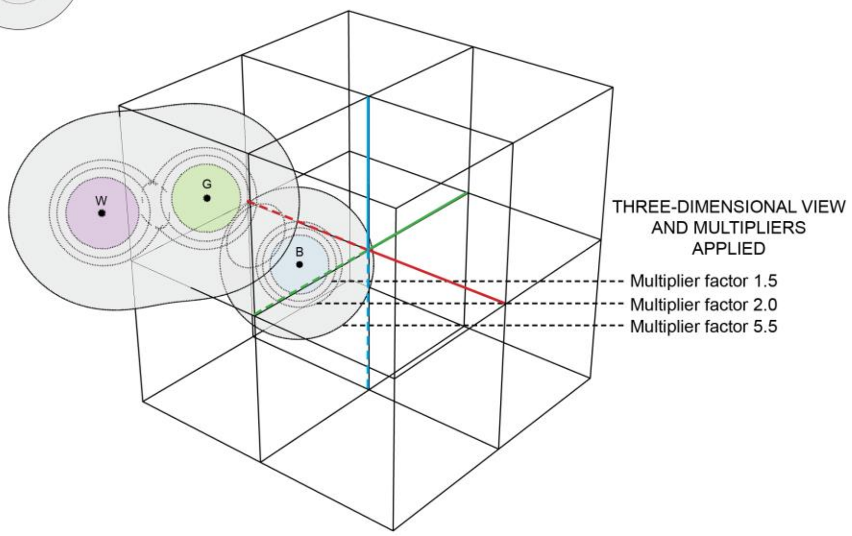
Appendix I. 3D Mood Box of Participant F on day 2



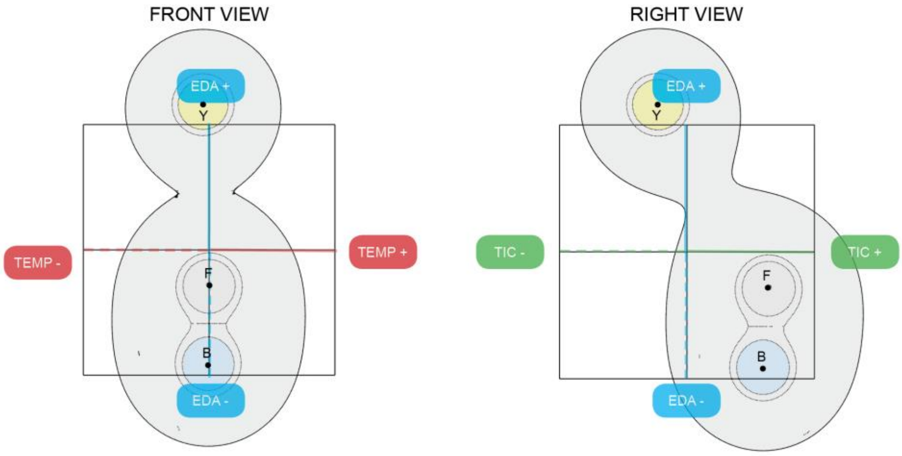


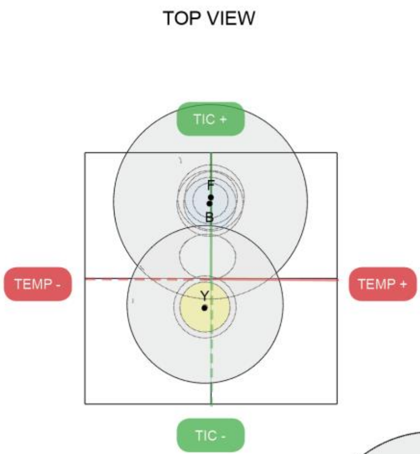


PARTICIPANT F - DAY 2				
COLOR	Q	tEDA	Temp	RPM tics
W	V	0.42	35.45	2.45
G	V	0.38	35.57	6.16
B	VIII	0.15	35.4	10.98

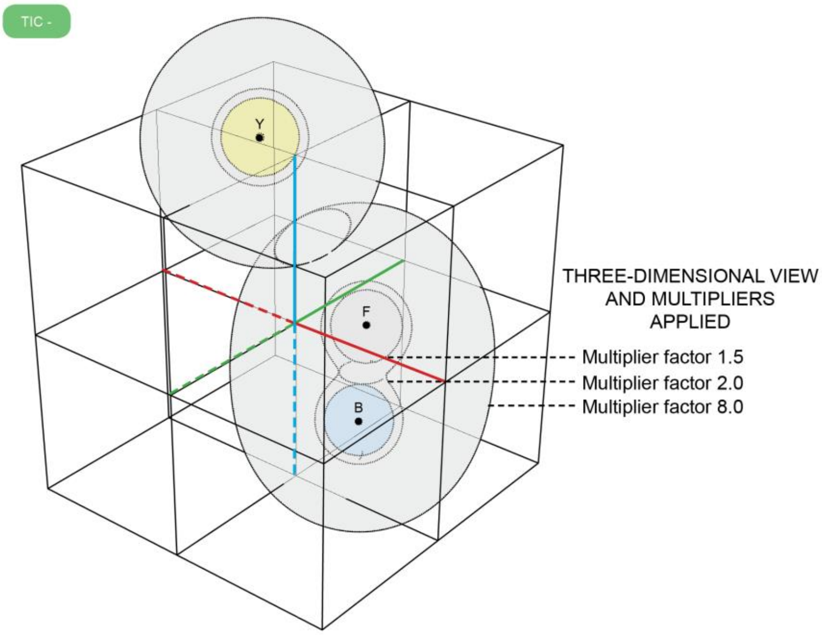


Appendix I. 3D Mood Box of Participant F on day 3



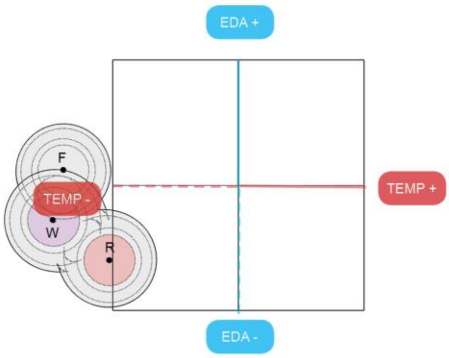


PARTICIPANT F - DAY 3				
COLOR	Q	tEDA	Temp	RPM tics
F	II	0.25	36.69	11.65
Y	V	0.61	36.63	7.30
B	II-VIII	0.09	36.68	11.42

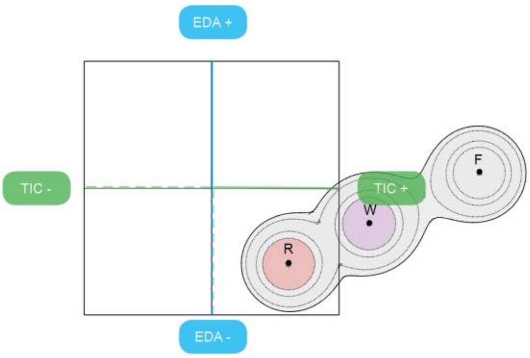


Appendix I. 3D Mood Box of Participant F on day 4

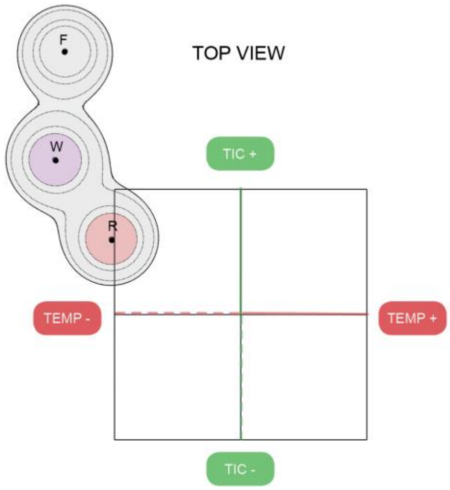
FRONT VIEW



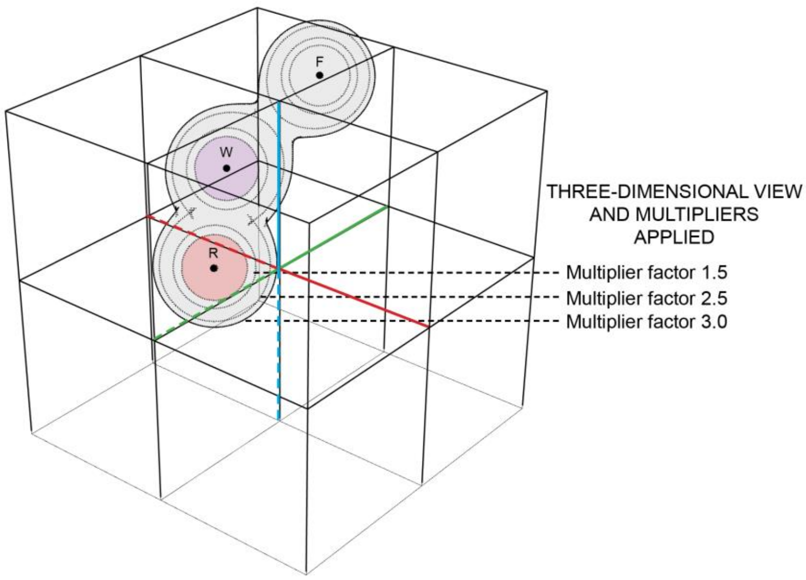
RIGHT VIEW



TOP VIEW

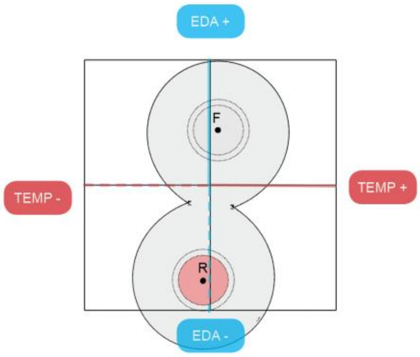


PARTICIPANT F - DAY 4				
COLOR	Q	tEDA	Temp	RPM tics
W	VIII	0.25	34.85	14.62
F	VII	0.35	34.95	18.95
R	VIII	0.17	35.41	11.45

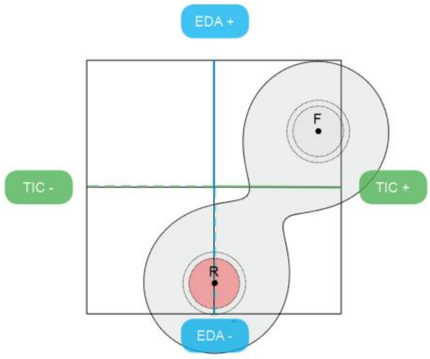


Appendix I. 3D Mood Box of Participant F on day 5

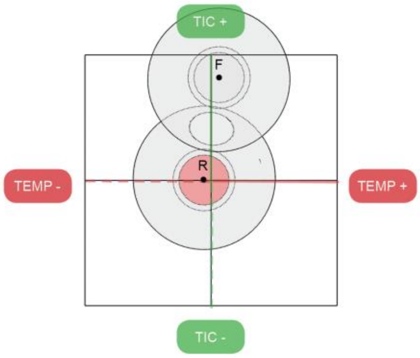
FRONT VIEW



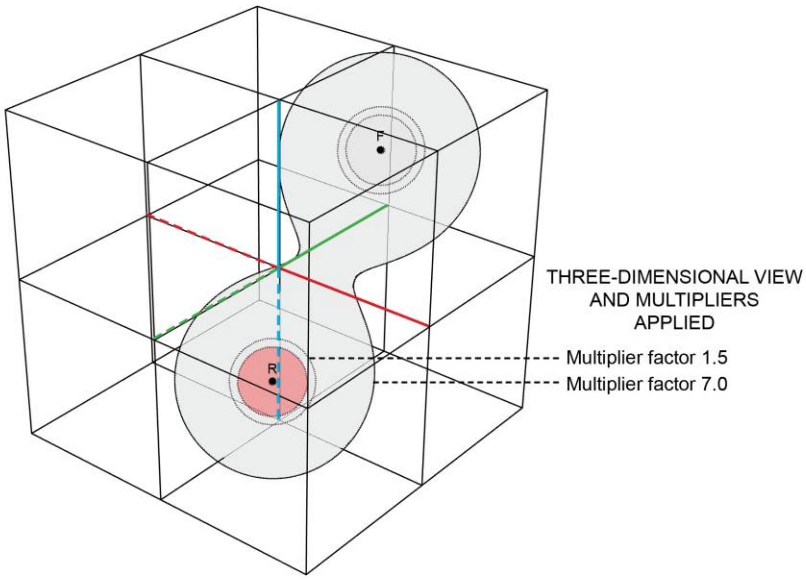
RIGHT VIEW



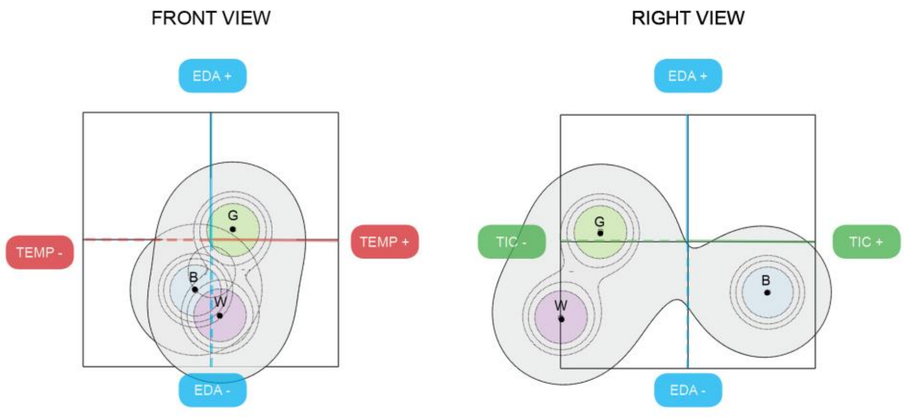
TOP VIEW

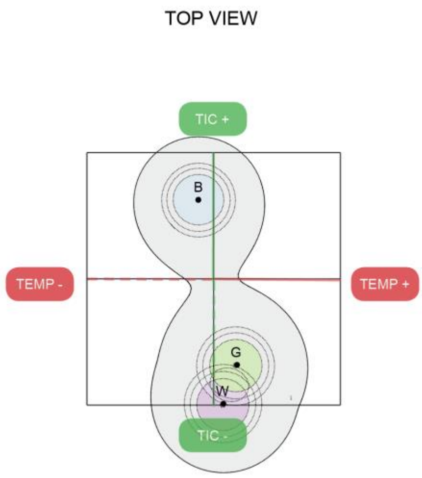


PARTICIPANT F - DAY 5				
COLOR	Q	tEDA	Temp	RPM tics
F	I	0.43	36.77	12.54
R	VII	0.13	36.62	8.45

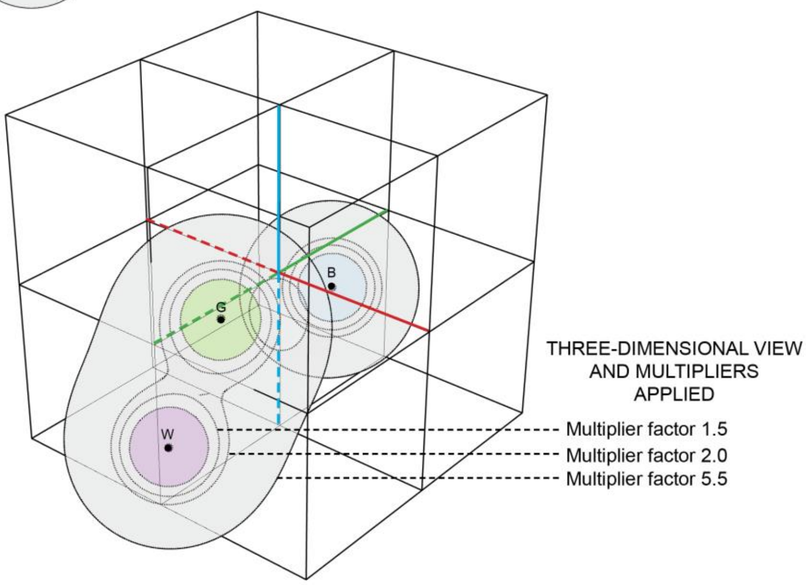


Appendix I. 3D Mood Box of Participant F on day 7

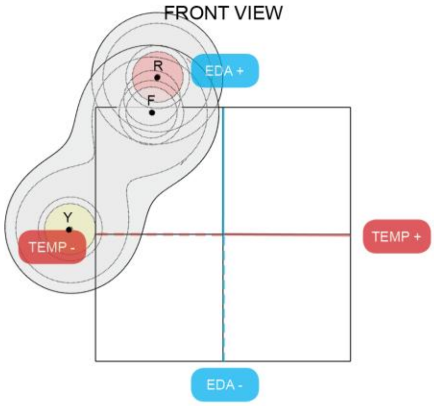


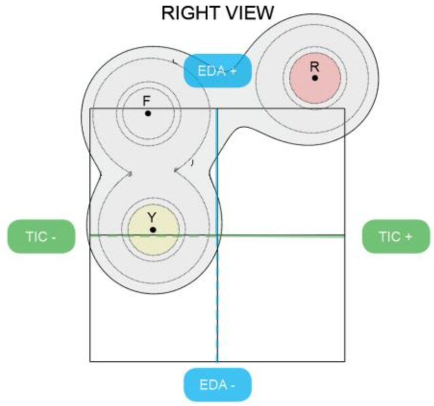


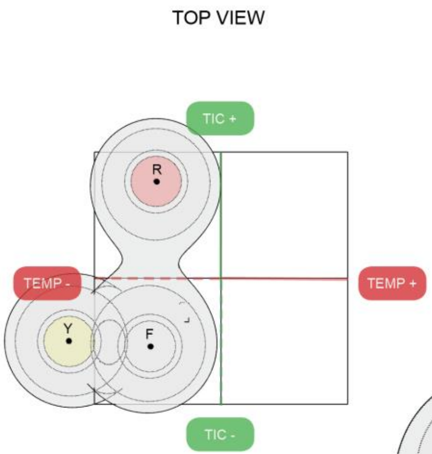
PARTICIPANT F - DAY 7				
COLOR	Q	tEDA	Temp	RPM tics
W	IV	0.17	36.78	3.45
G	III	0.34	36.91	5.01
B	VIII	0.22	36.54	11.58



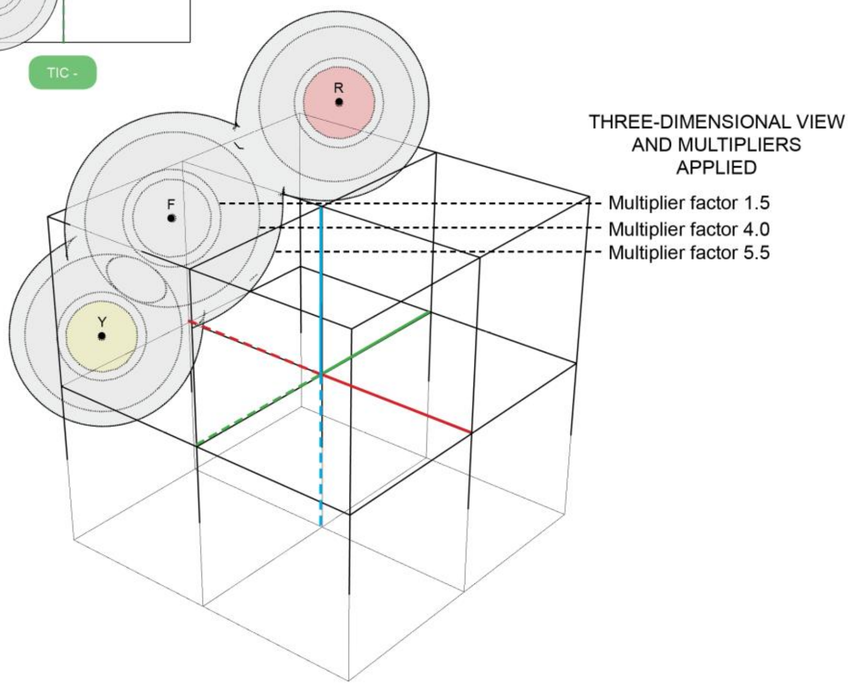
Appendix I. 3D Mood Box of Participant F on day 8



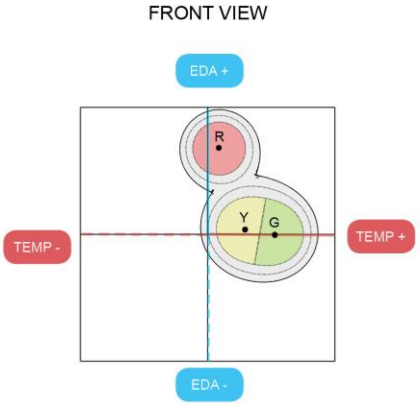


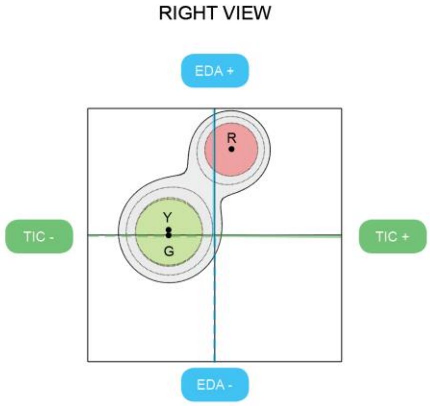


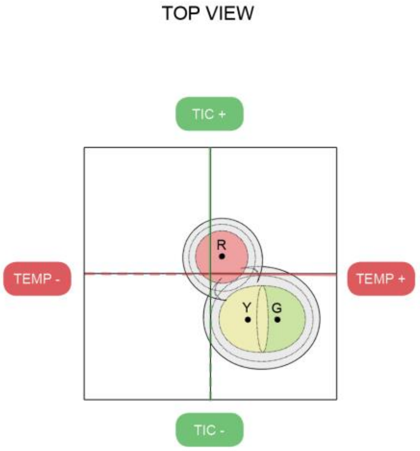
PARTICIPANT F - DAY 8				
COLOR	Q	tEDA	Temp	RPM tics
F	V	0.56	35.99	5.73
Y	V	0.33	35.19	5.93
R	VII	0.63	36.05	12.28



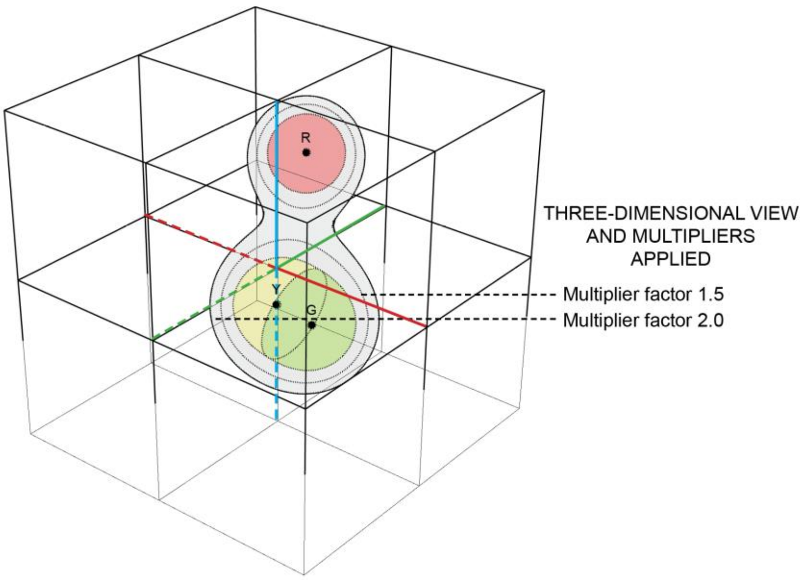
Appendix I. 3D Mood Box of Participant F on day 9



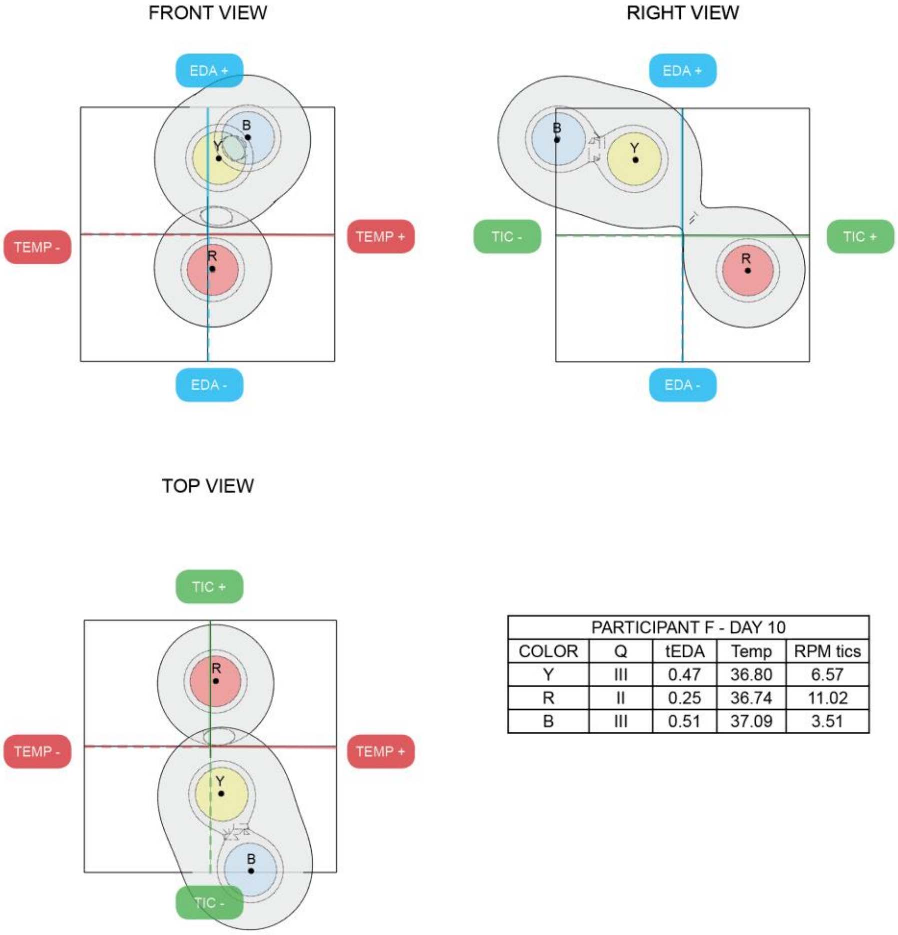




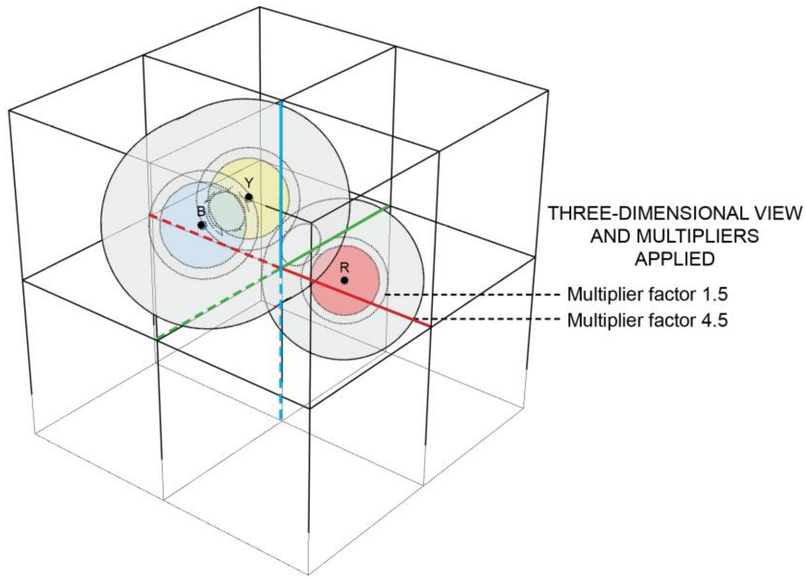
PARTICIPANT F - DAY 9				
COLOR	Q	tEDA	Temp	RPM tics
Y	III	0.33	37.06	6.62
G	III	0.32	37.35	6.63
R	I	0.49	36.80	9.11



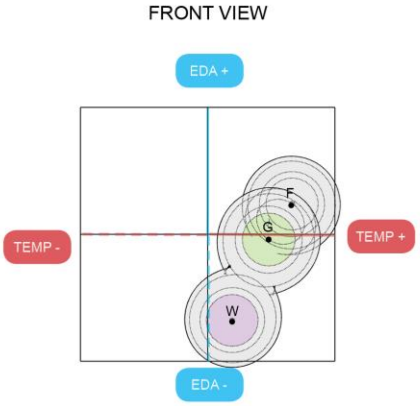
Appendix I. 3D Mood Box of Participant F on day 10

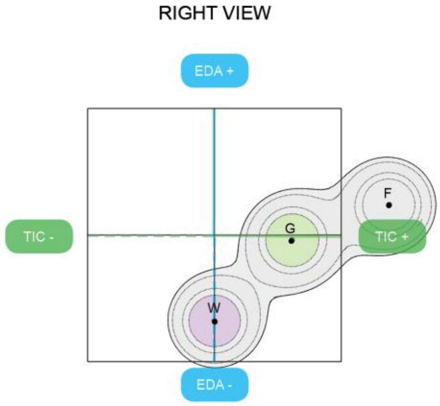


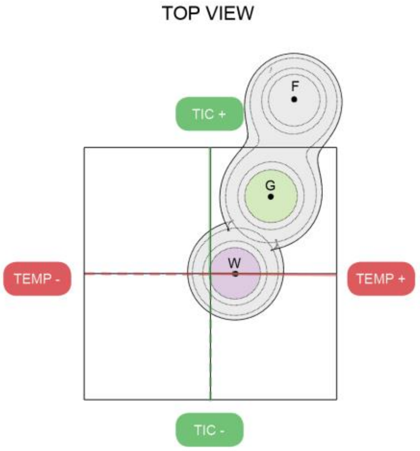
PARTICIPANT F - DAY 10				
COLOR	Q	tEDA	Temp	RPM tics
Y	III	0.47	36.80	6.57
R	II	0.25	36.74	11.02
B	III	0.51	37.09	3.51



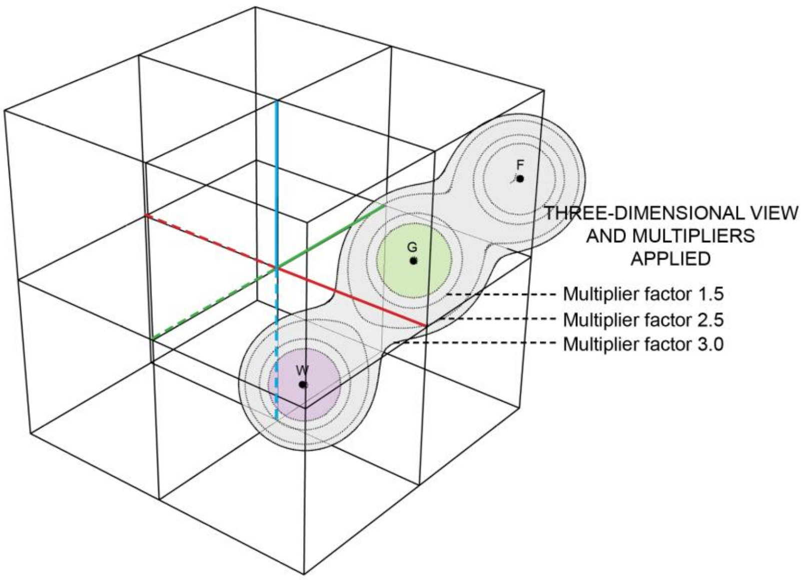
Appendix I. 3D Mood Box of Participant F on day 11



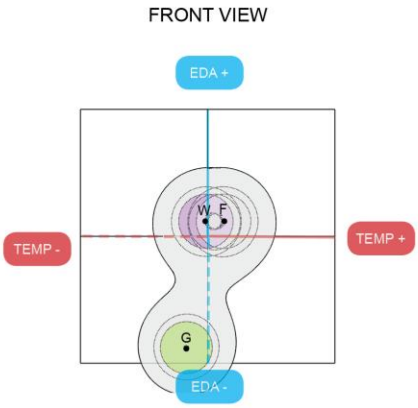


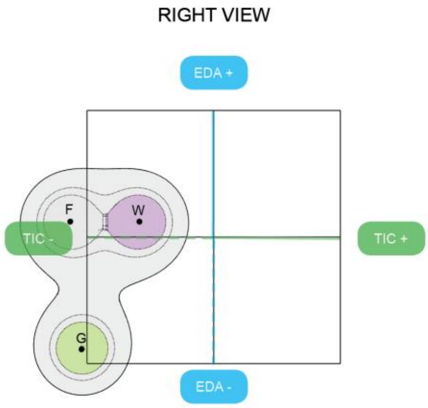


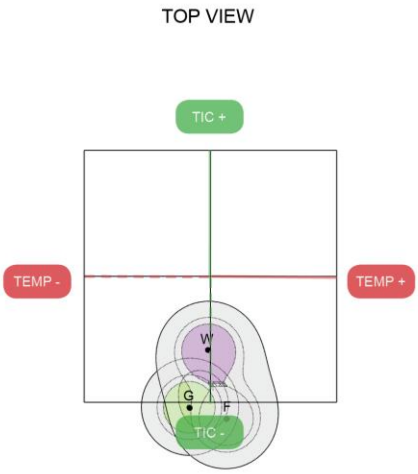
PARTICIPANT F - DAY 11				
COLOR	Q	tEDA	Temp	RPM tics
W	II-IV	0.15	36.93	8.44
F	I	0.38	37.52	15.33
G	I-II	0.31	37.29	11.50



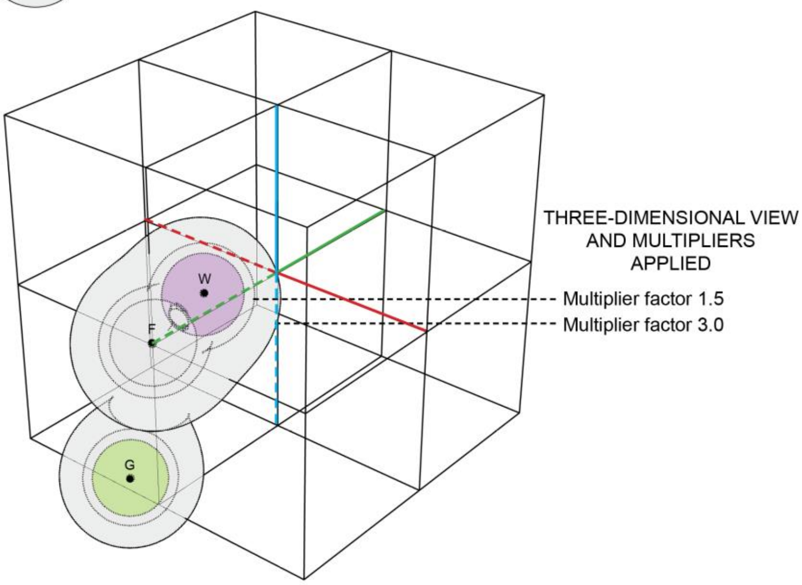
Appendix I. 3D Mood Box of Participant F on day 12



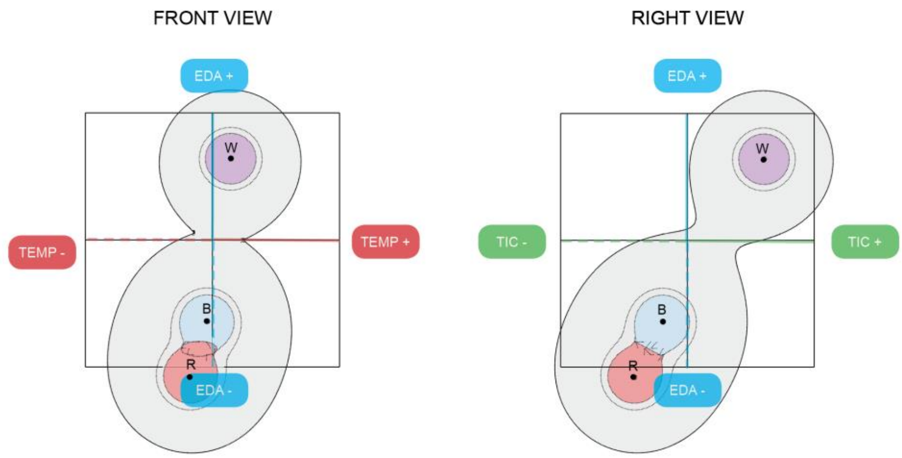


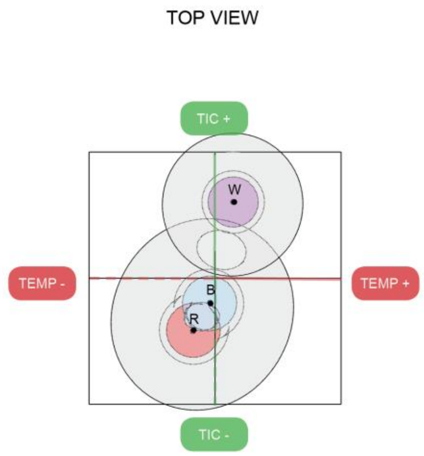


PARTICIPANT F - DAY 12				
COLOR	Q	tEDA	Temp	RPM tics
W	III-V	0.35	36.67	5.51
F	III	0.35	36.85	2.77
G	VI	0.10	36.48	3.24

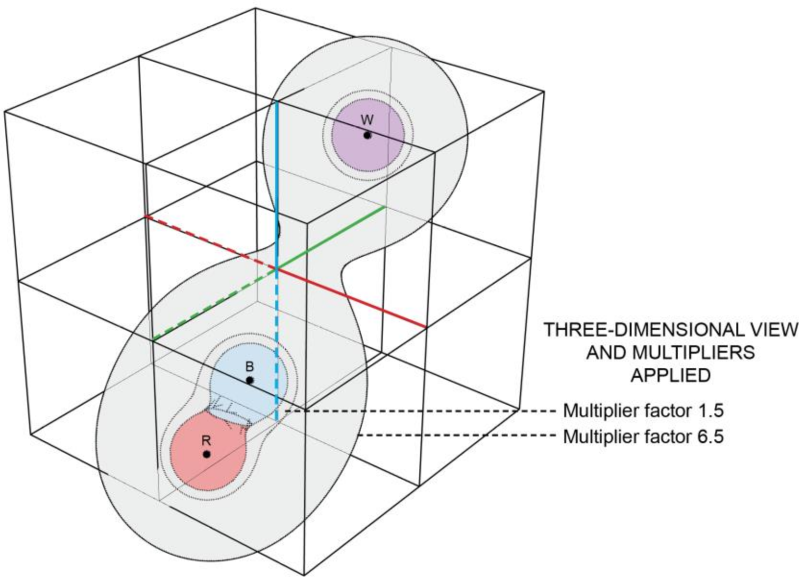


Appendix I. 3D Mood Box of Participant F on day 13

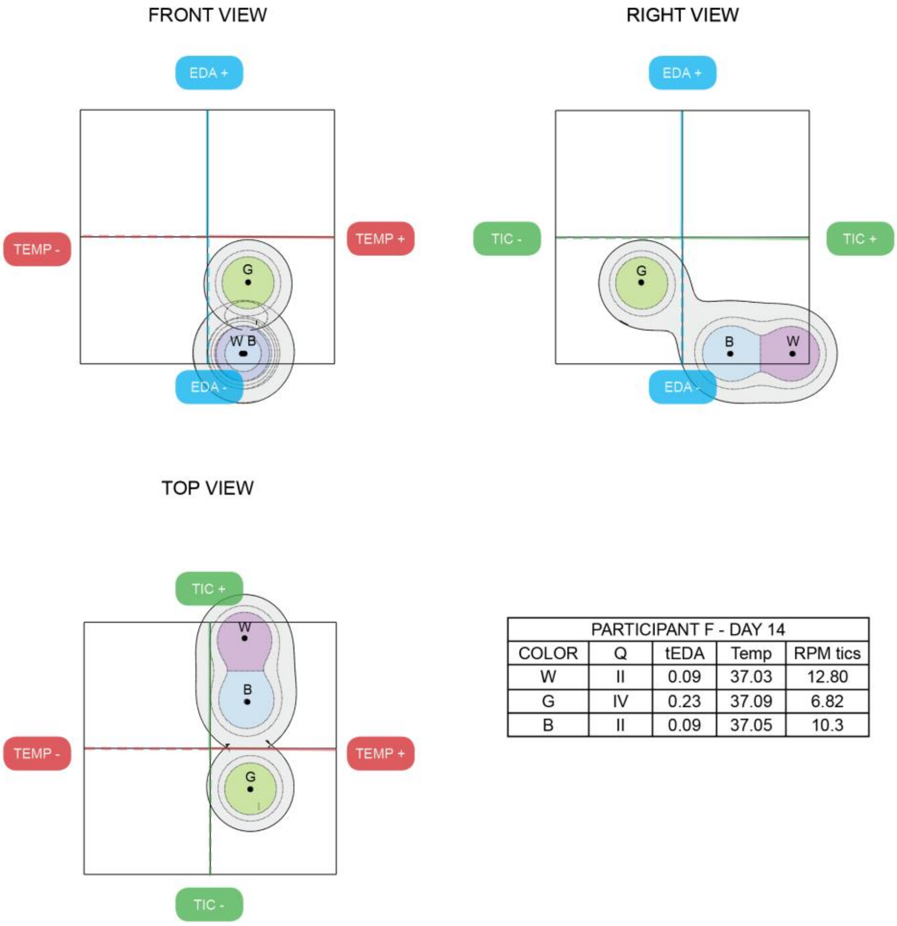




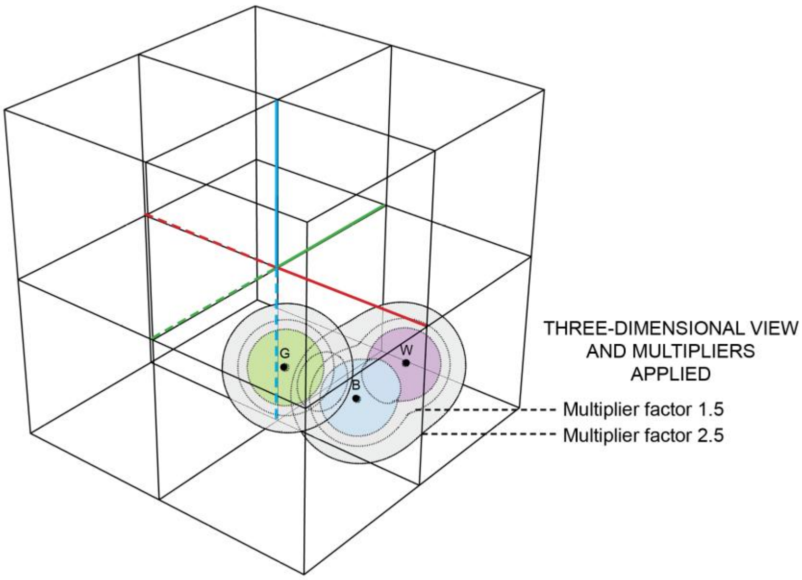
PARTICIPANT F - DAY 13				
COLOR	Q	tEDA	Temp	RPM tics
W	I	0.48	36.87	11.46
R	VI	0.05	36.47	6.34
B	VI	0.16	36.64	7.47



Appendix I. 3D Mood Box of Participant F on day 14

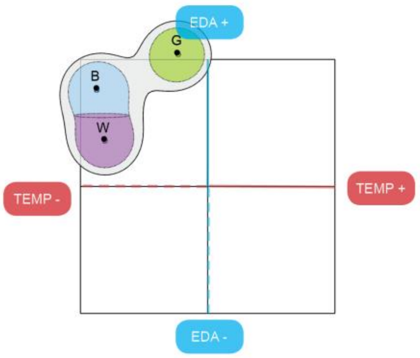


PARTICIPANT F - DAY 14				
COLOR	Q	tEDA	Temp	RPM tics
W	II	0.09	37.03	12.80
G	IV	0.23	37.09	6.82
B	II	0.09	37.05	10.3

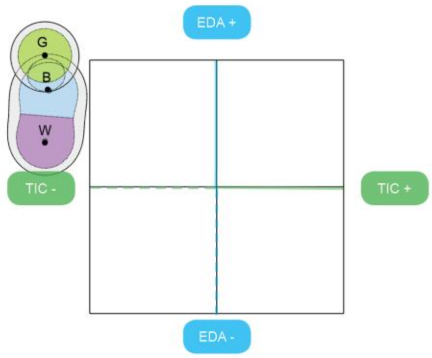


Appendix I. 3D Mood Box of Participant FX on day 2

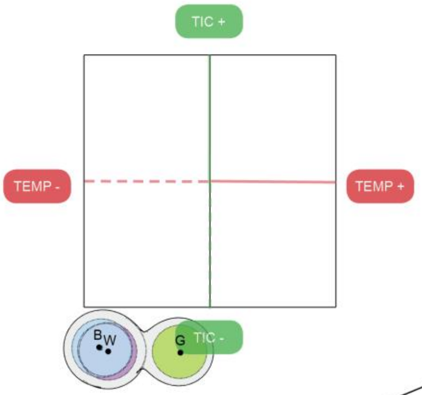
FRONT VIEW



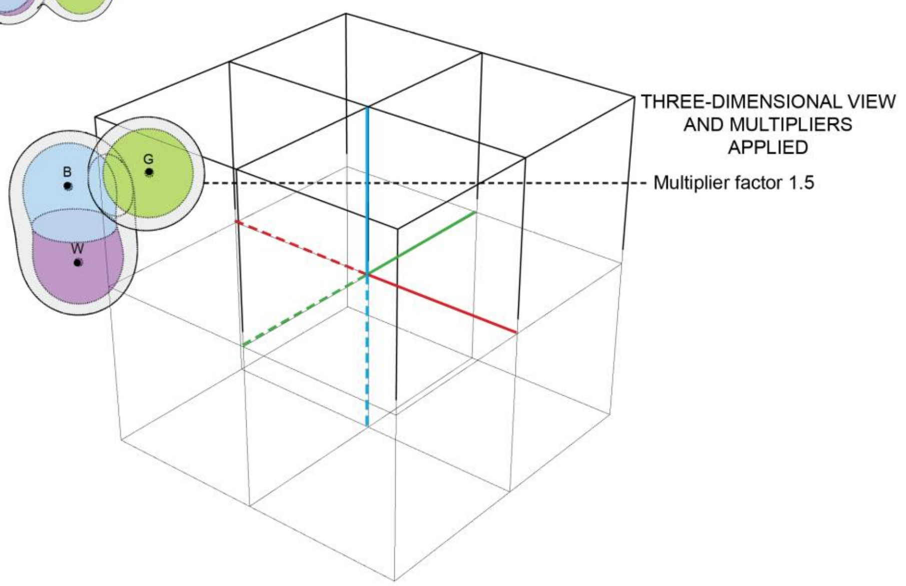
RIGHT VIEW



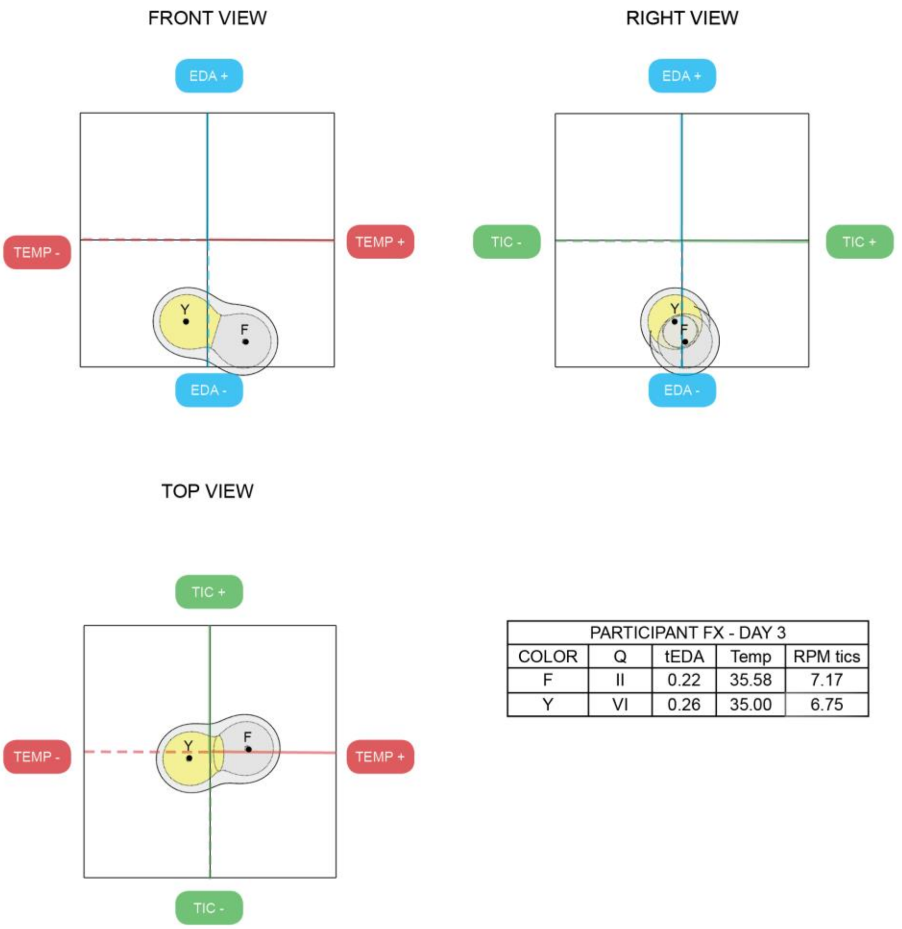
TOP VIEW



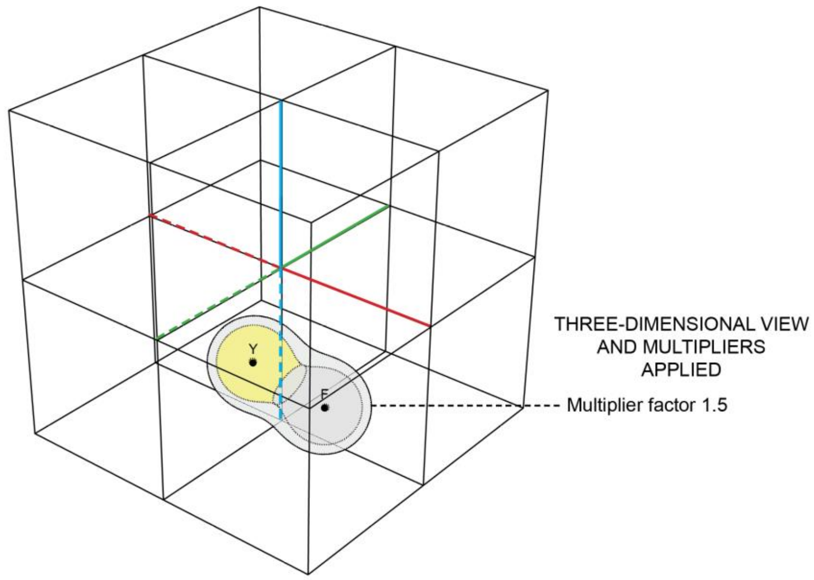
PARTICIPANT FX - DAY 2				
COLOR	Q	tEDA	Temp	RPM tics
W	V	0.51	34.2	0.28
G	V	0.68	34.92	0.27
B	V	0.61	34.12	0.43



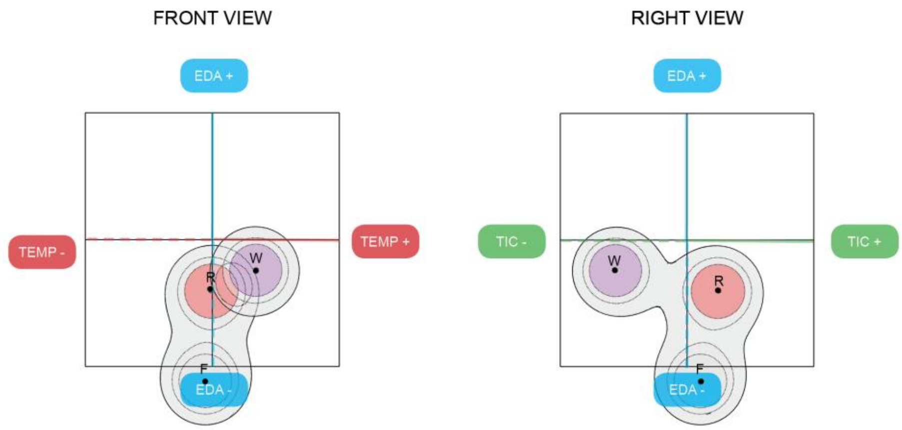
Appendix I. 3D Mood Box of Participant FX on day 3

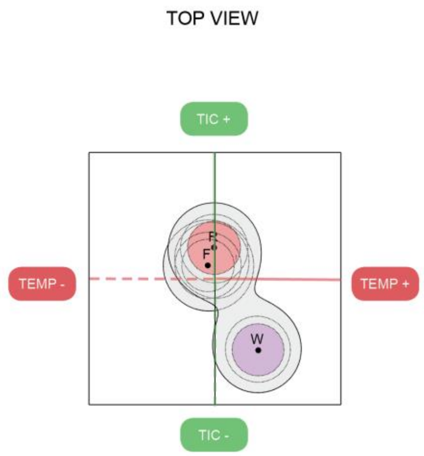


PARTICIPANT FX - DAY 3				
COLOR	Q	tEDA	Temp	RPM tics
F	II	0.22	35.58	7.17
Y	VI	0.26	35.00	6.75

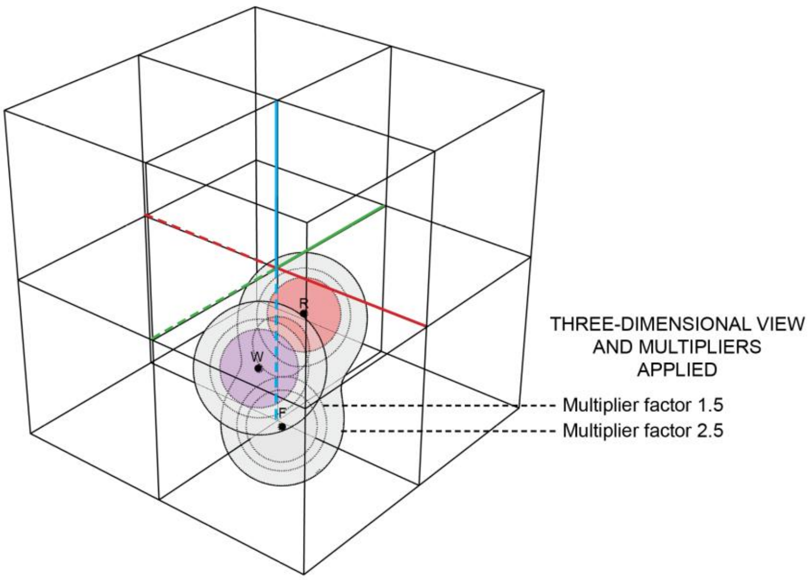


Appendix I. 3D Mood Box of Participant FX on day 4



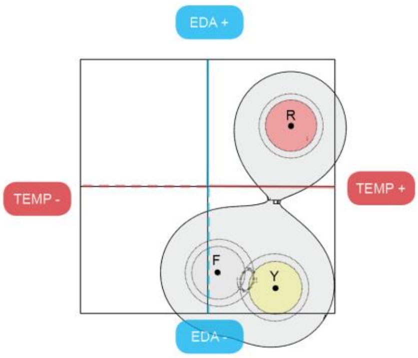


PARTICIPANT FX - DAY 4				
COLOR	Q	tEDA	Temp	RPM tics
W	IV	0.36	35.64	4.20
F	VIII	0.14	35.14	7.56
R	II-VIII	0.32	35.20	8.28

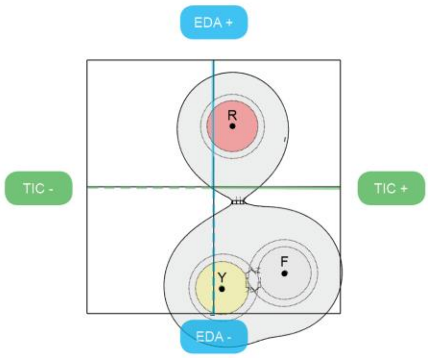


Appendix I. 3D Mood Box of Participant FX on day 5

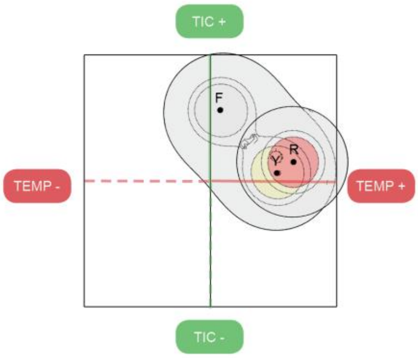
FRONT VIEW



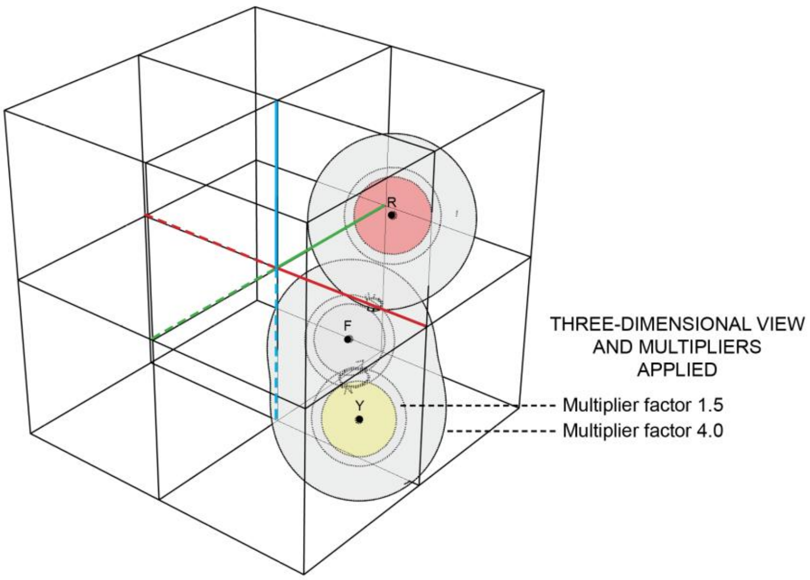
RIGHT VIEW



TOP VIEW

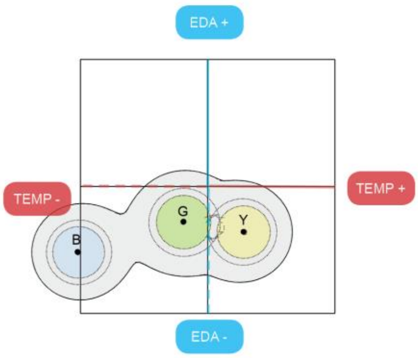


PARTICIPANT FX - DAY 5				
COLOR	Q	tEDA	Temp	RPM tics
F	II	0.25	35.31	9.86
Y	II	0.22	35.88	7.35
R	I	0.54	36.03	7.78

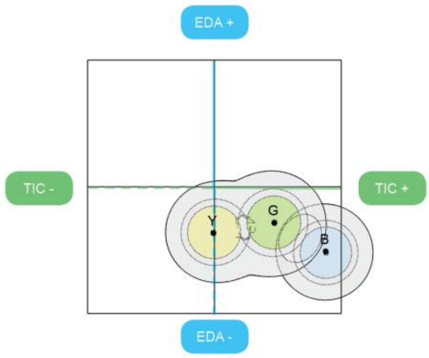


Appendix I. 3D Mood Box of Participant FX on day 6

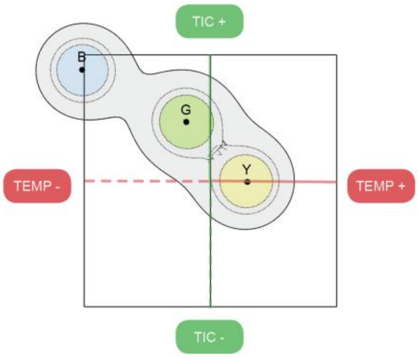
FRONT VIEW



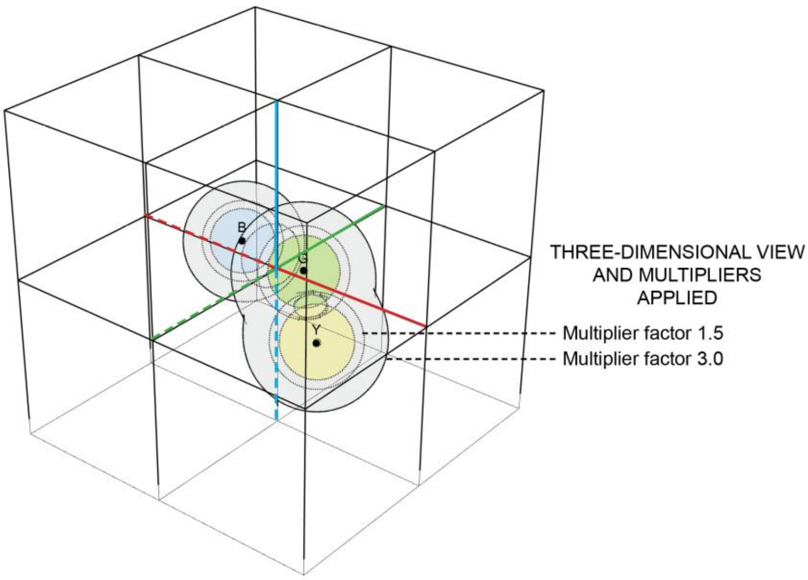
RIGHT VIEW



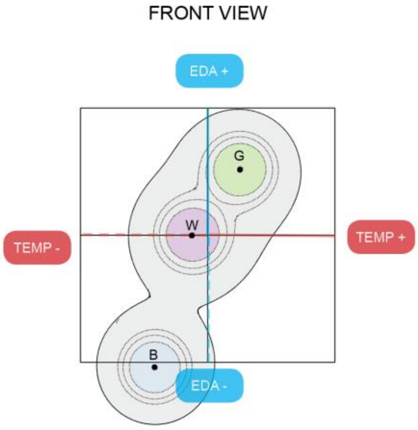
TOP VIEW

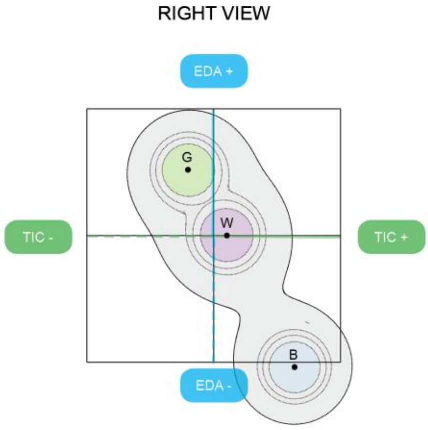


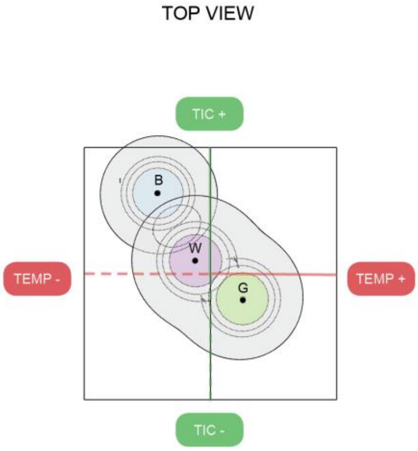
PARTICIPANT FX - DAY 6				
COLOR	Q	tEDA	Temp	RPM tics
Y	II-IV	0.33	35.57	7.00
G	VIII	0.35	34.97	9.40
B	VIII	0.29	33.94	11.44



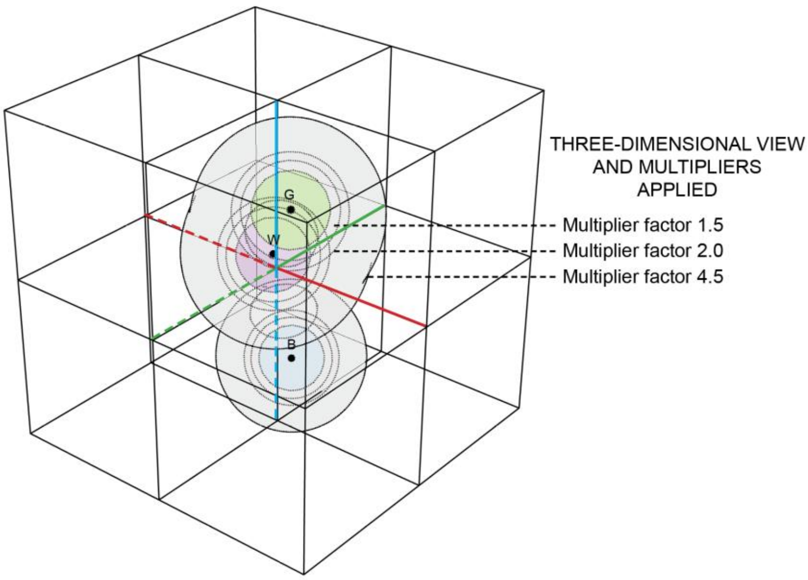
Appendix I. 3D Mood Box of Participant FX on day 7





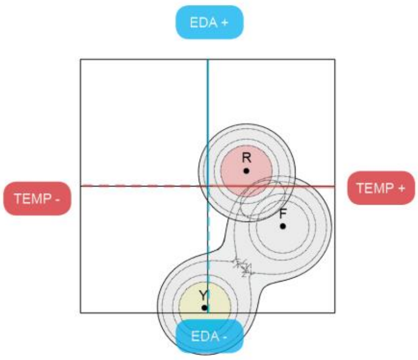


PARTICIPANT FX - DAY 7				
COLOR	Q	tEDA	Temp	RPM tics
W	VII-VIII	0.42	35.06	7.56
G	III	0.55	35.53	6.03
B	VIII	0.16	34.69	10.23

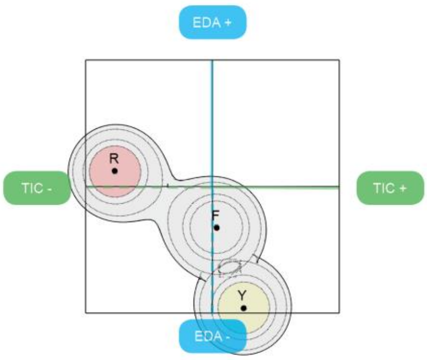


Appendix I. 3D Mood Box of Participant FX on day 8

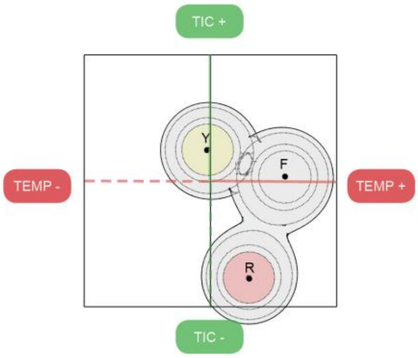
FRONT VIEW



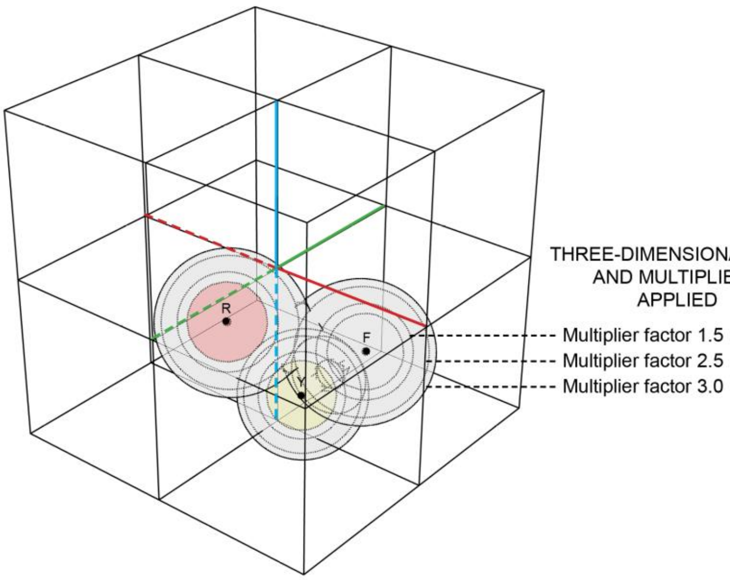
RIGHT VIEW



TOP VIEW

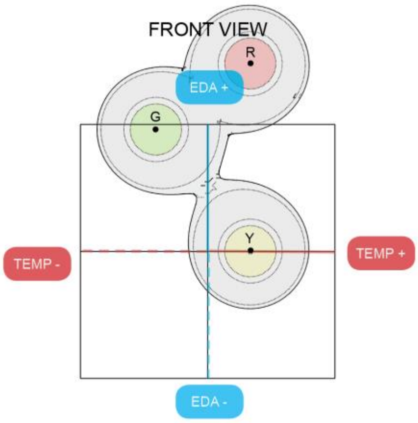


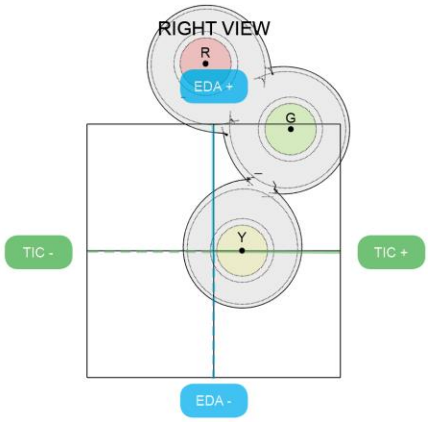
PARTICIPANT FX - DAY 8				
COLOR	Q	tEDA	Temp	RPM tics
F	II	0.34	35.95	7.20
Y	VIII	0.18	35.18	8.28
R	III	0.45	34.59	3.19

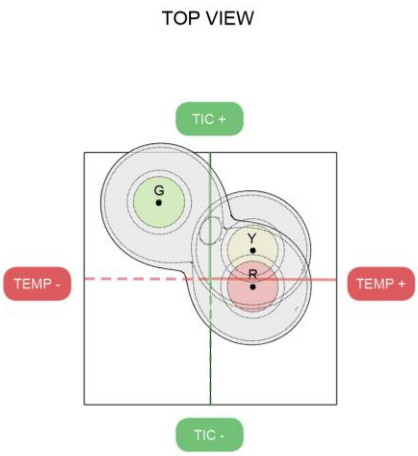


THREE-DIMENSIONAL VIEW AND MULTIPLIERS APPLIED

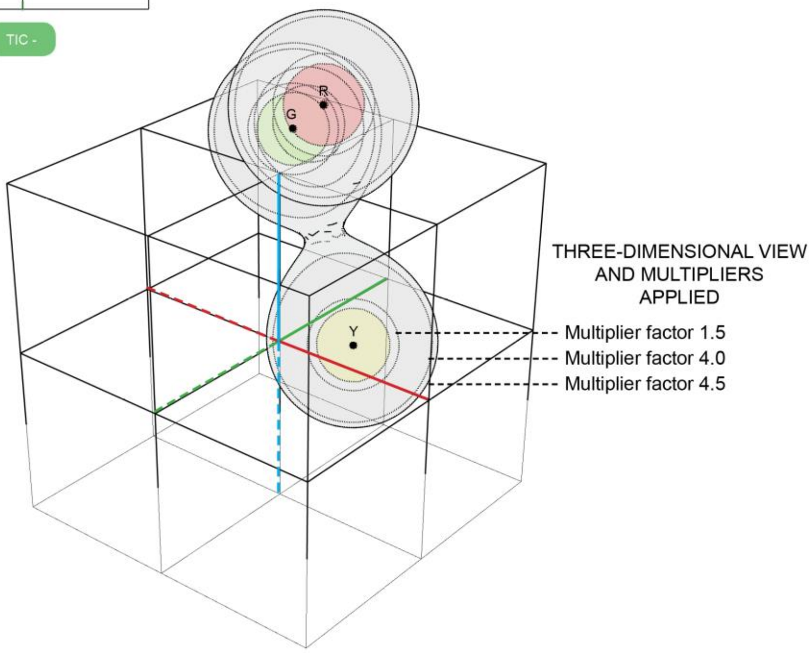
Appendix I. 3D Mood Box of Participant FX on day 9





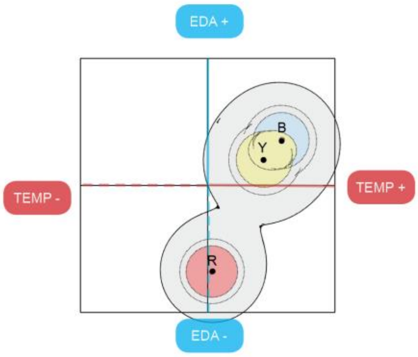


PARTICIPANT FX - DAY 9				
COLOR	Q	tEDA	Temp	RPM tics
Y	I-II	0.42	35.63	8.16
G	VII	0.66	34.70	10.08
R	III	0.79	35.63	6.72

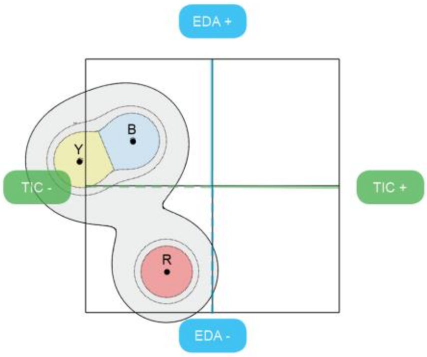


Appendix I. 3D Mood Box of Participant FX on day 10

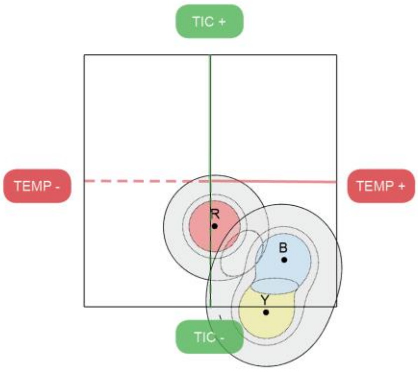
FRONT VIEW



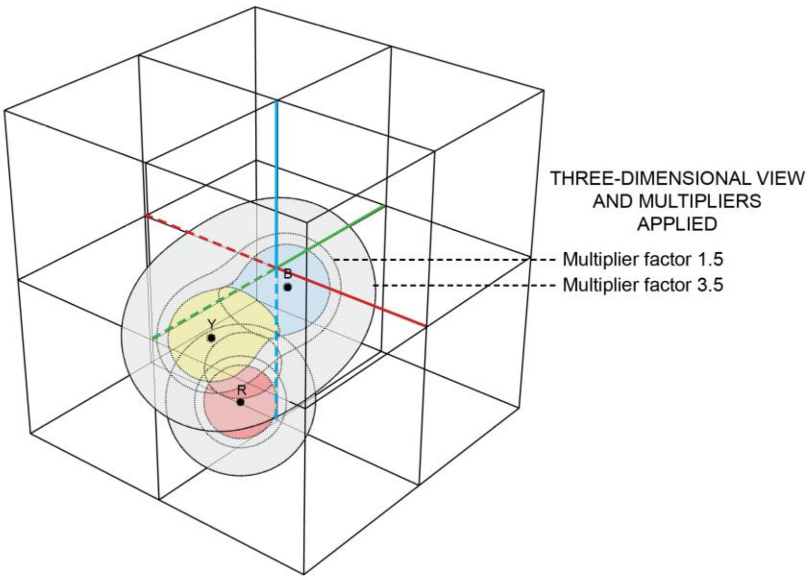
RIGHT VIEW



TOP VIEW

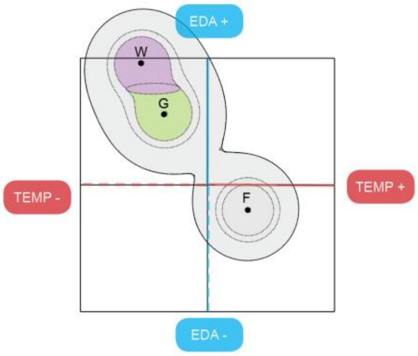


PARTICIPANT FX - DAY 10				
COLOR	Q	tEDA	Temp	RPM tics
Y	III	0.47	35.76	1.83
R	IV	0.25	35.25	5.24
B	III	0.51	35.94	3.90

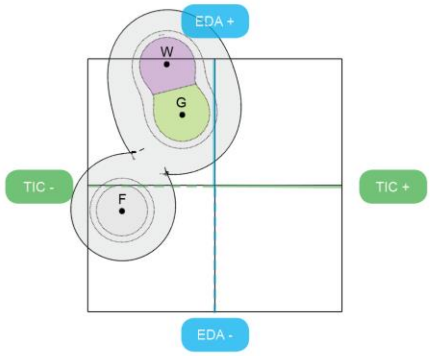


Appendix I. 3D Mood Box of Participant FX on day 12

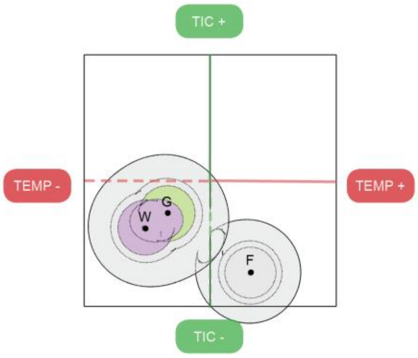
FRONT VIEW



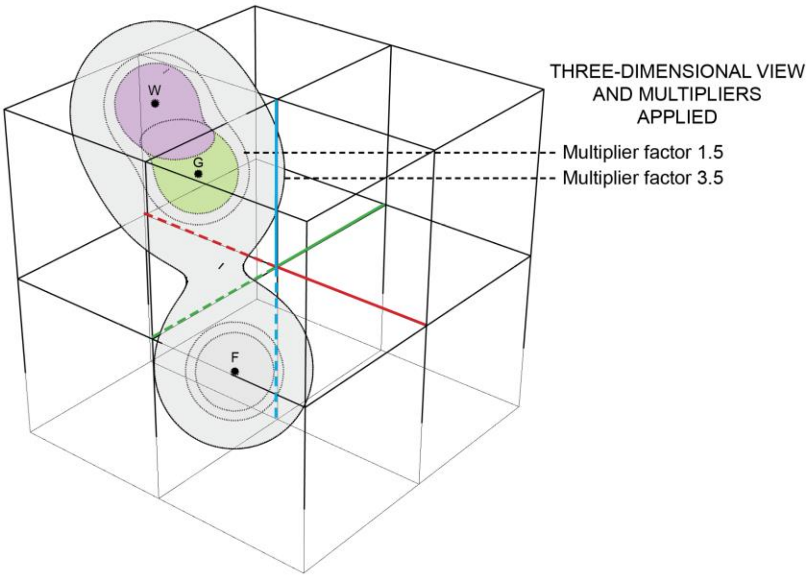
RIGHT VIEW



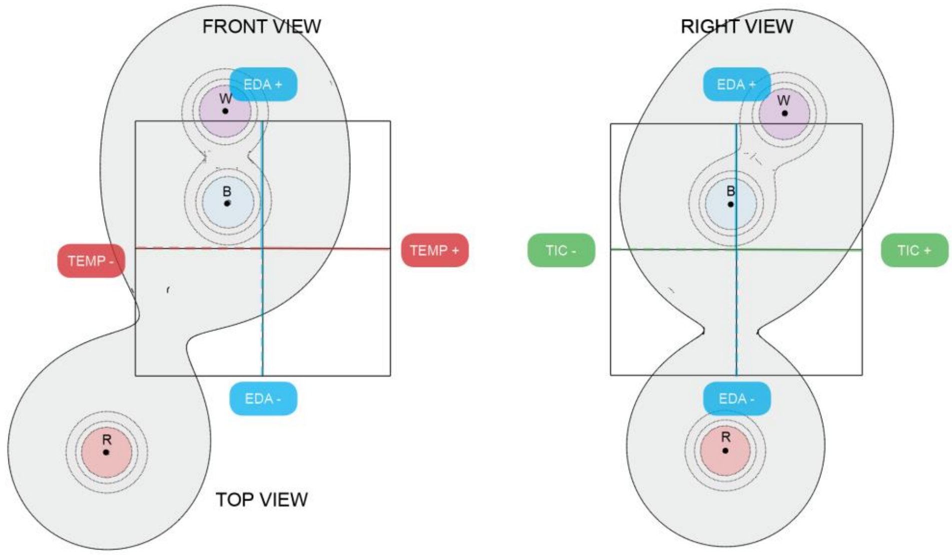
TOP VIEW

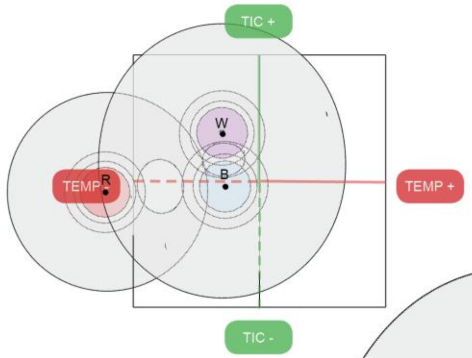


PARTICIPANT FX - DAY 12				
COLOR	Q	tEDA	Temp	RPM tics
W	V	0.66	34.56	5.15
F	IV	0.37	35.61	3.38
G	V	0.56	34.79	5.76

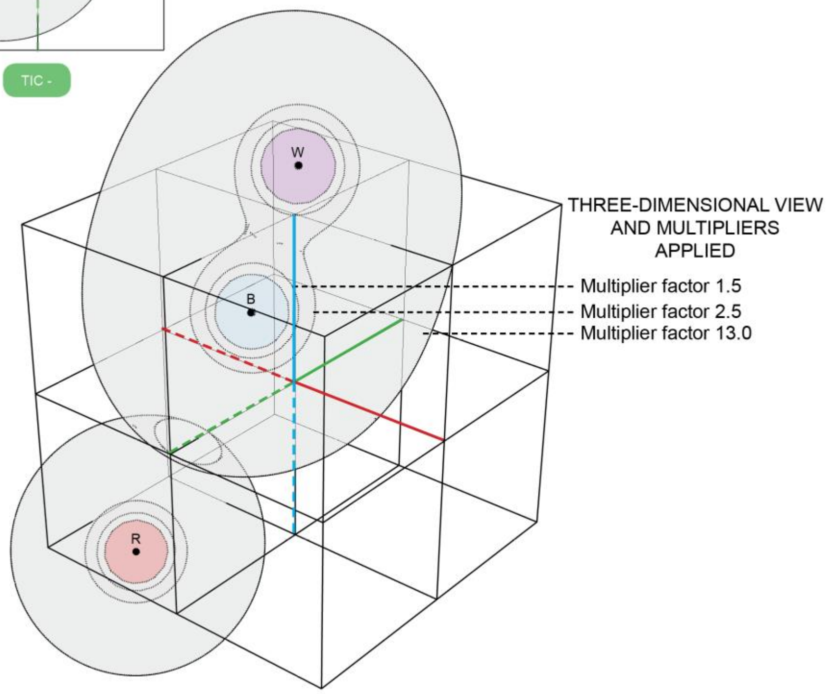


Appendix I. 3D Mood Box of Participant FX on day 13

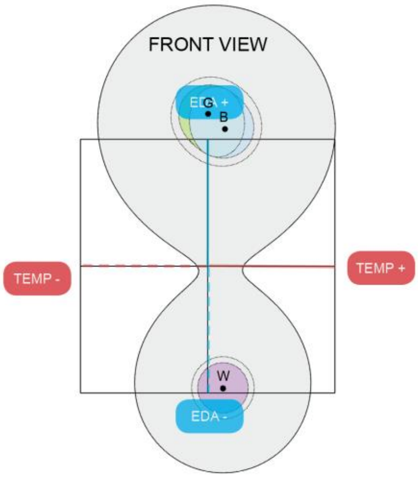


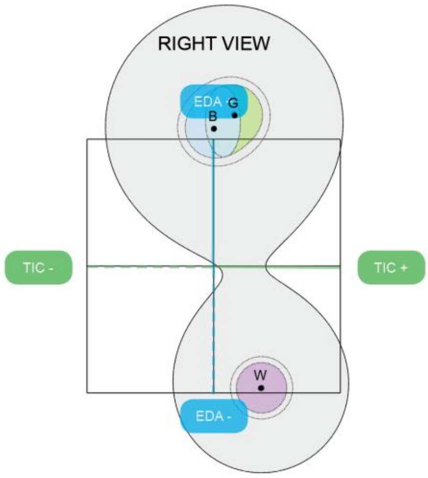


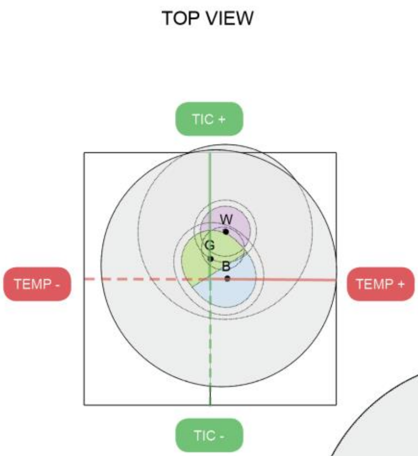
PARTICIPANT FX - DAY 13				
COLOR	Q	tEDA	Temp	RPM tics
W	VII	0.69	34.84	8.97
R	VI	0.02	33.68	6.60
B	V	0.51	34.87	6.82



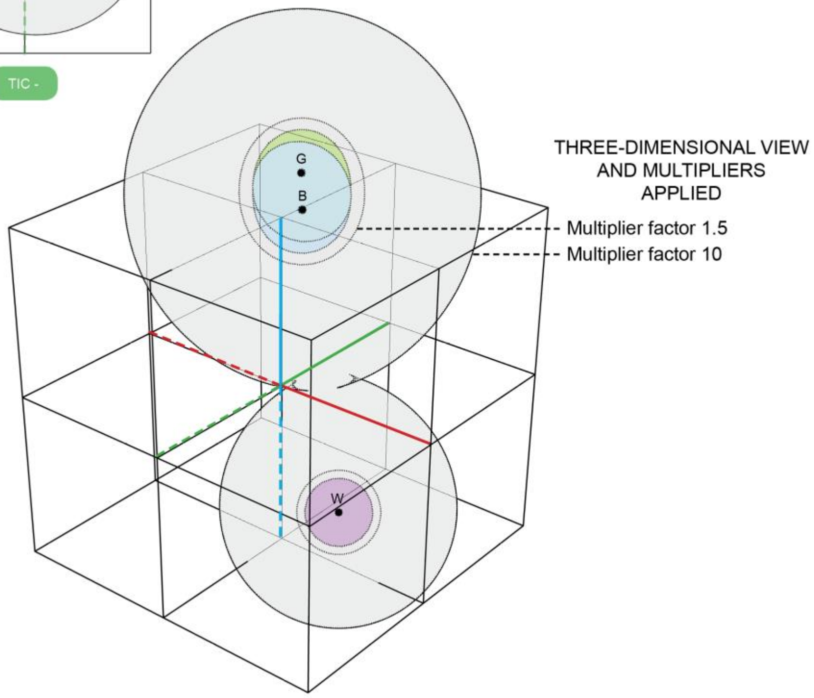
Appendix I. 3D Mood Box of Participant FX on day 14



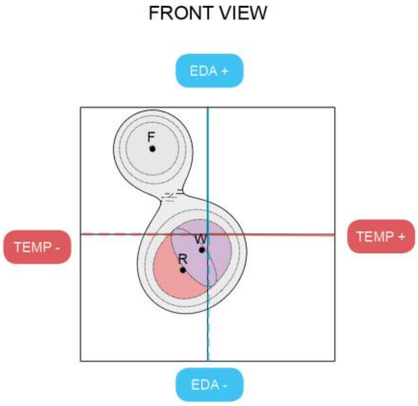


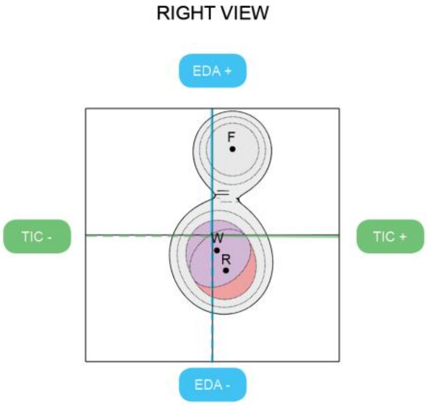


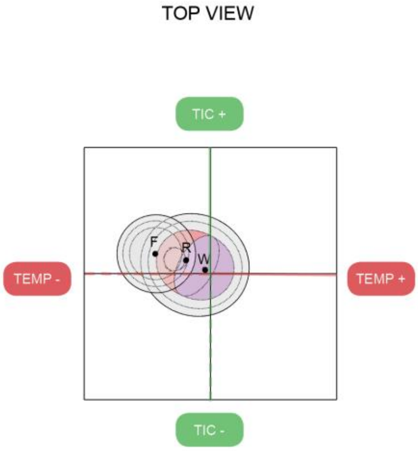
PARTICIPANT FX - DAY 14				
COLOR	Q	tEDA	Temp	RPM tics
W	II	0.18	35.36	8.93
G	V-VII	0.72	35.21	7.84
B	I-III	0.69	35.38	7.04



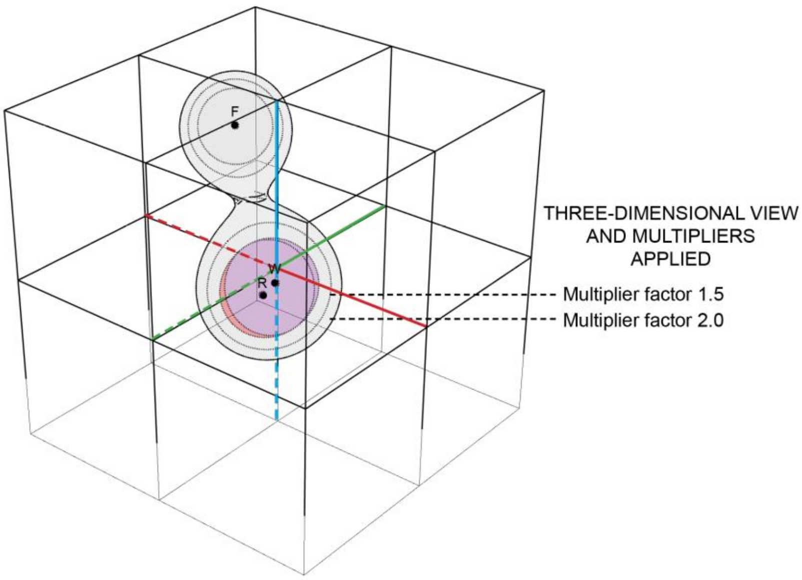
Appendix I. 3D Mood Box of Participant H on day 4



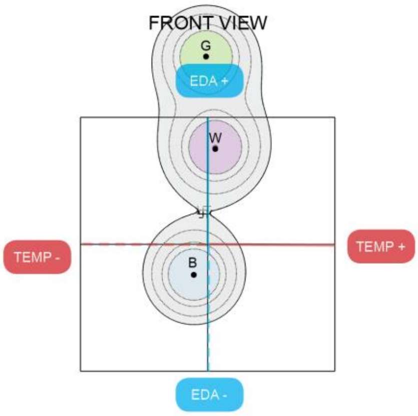


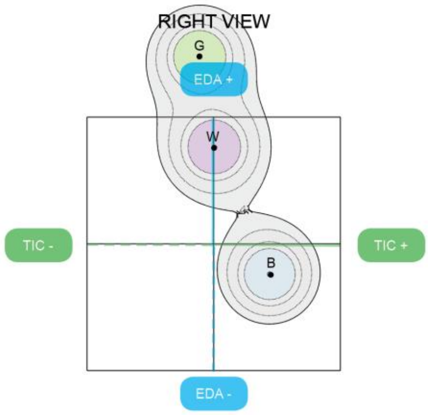


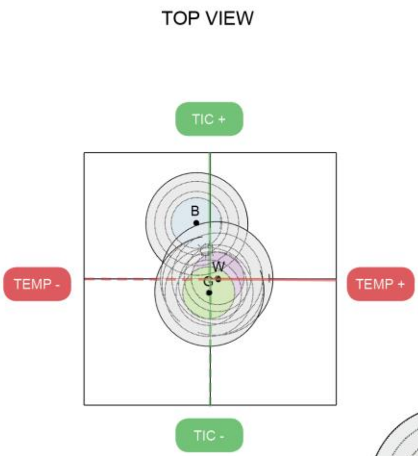
PARTICIPANT H - DAY 4				
COLOR	Q	tEDA	Temp	RPM tics
W	VIII	0.13	36.45	1.33
F	VII	0.33	35.96	1.96
R	VIII	0.09	36.26	1.68



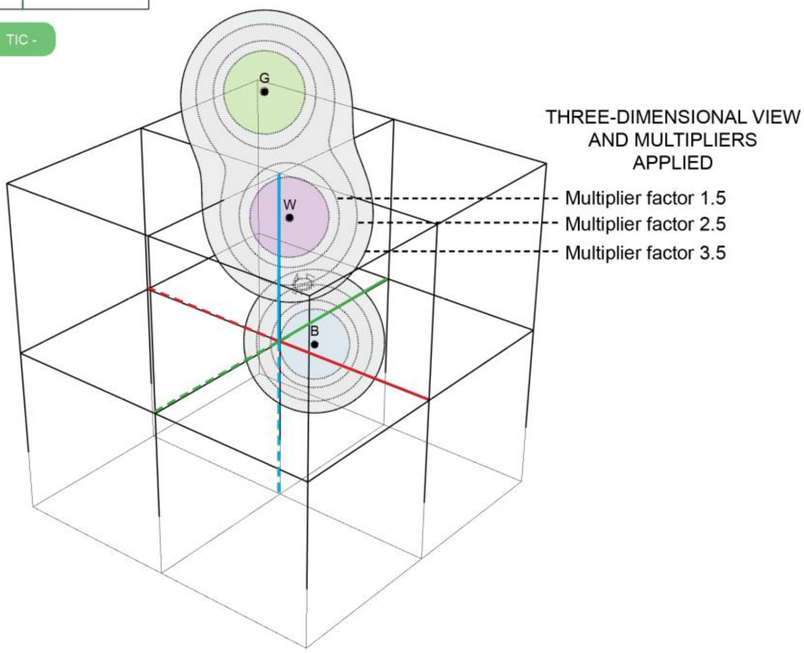
Appendix I. 3D Mood Box of Participant H on day 7



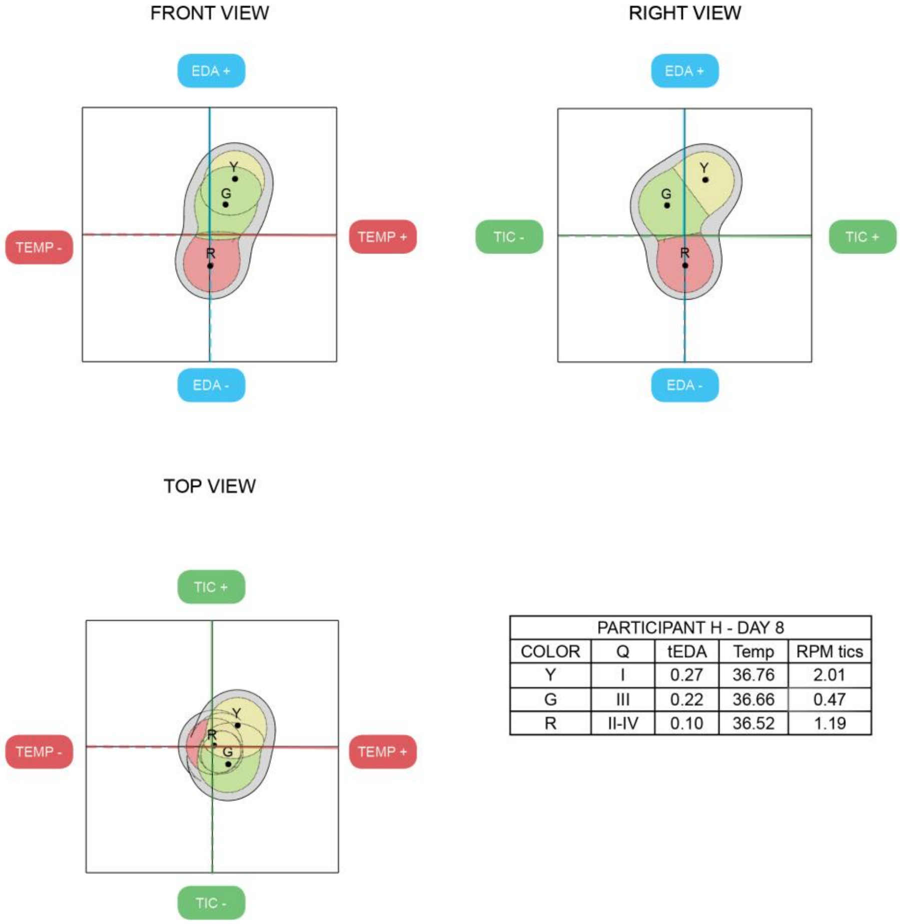




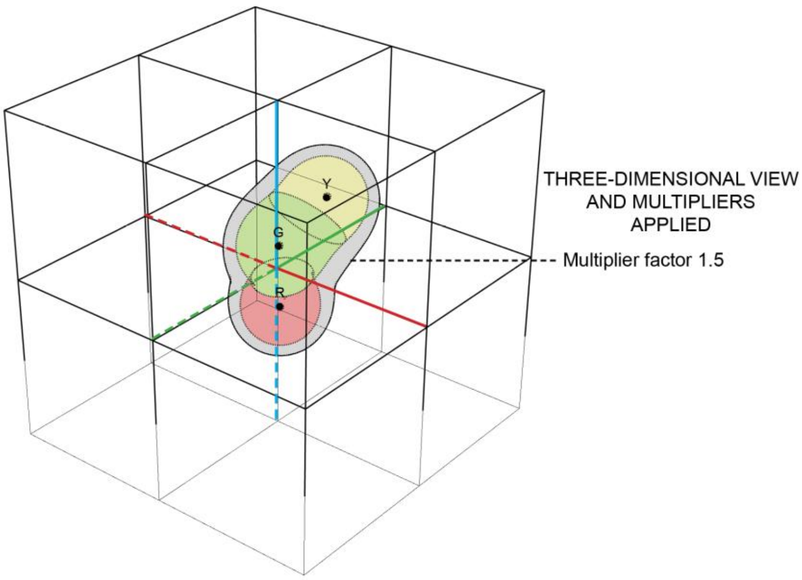
PARTICIPANT H - DAY 7				
COLOR	Q	tEDA	Temp	RPM tics
W	I-III	0.35	36.58	1.19
G	III-V	0.53	36.49	0.61
B	VIII	0.10	36.37	3.38



Appendix I. 3D Mood Box of Participant H on day 8

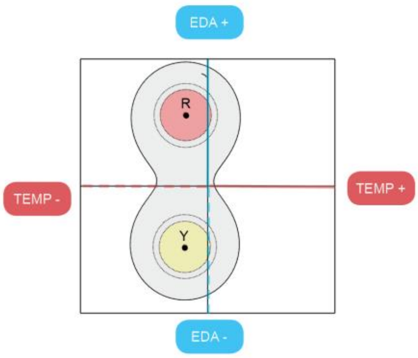


PARTICIPANT H - DAY 8				
COLOR	Q	tEDA	Temp	RPM tics
Y	I	0.27	36.76	2.01
G	III	0.22	36.66	0.47
R	II-IV	0.10	36.52	1.19

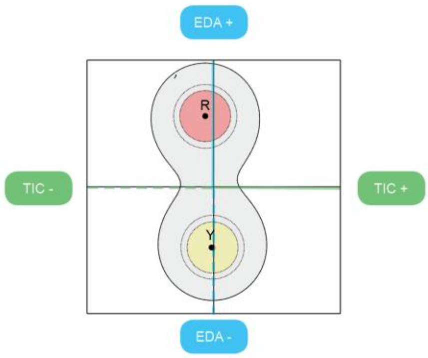


Appendix I. 3D Mood Box of Participant H on day 10

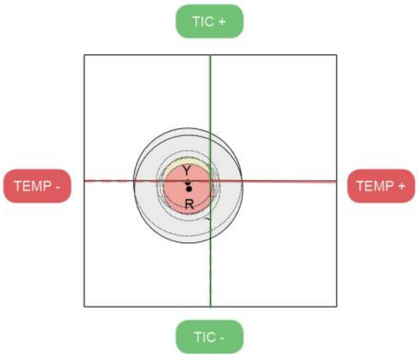
FRONT VIEW



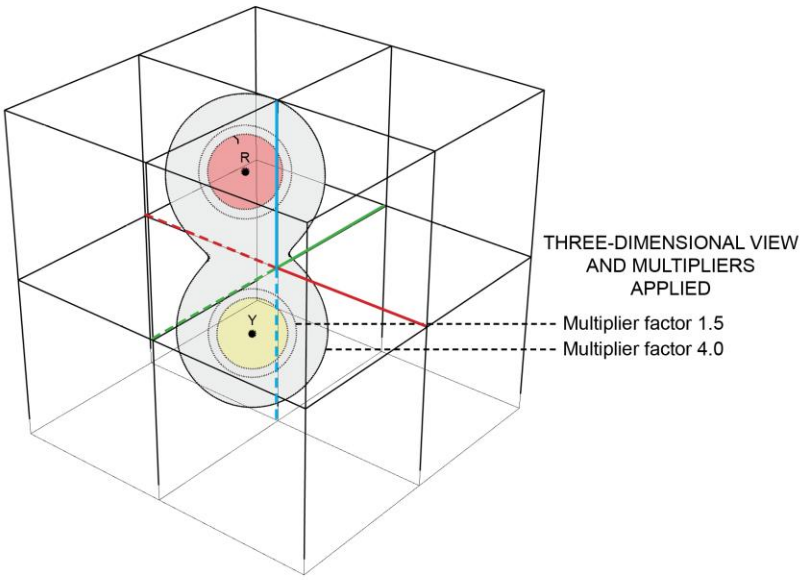
RIGHT VIEW



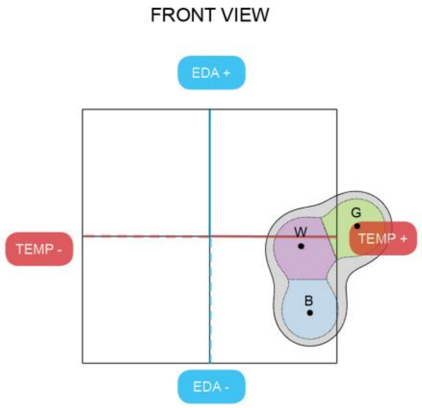
TOP VIEW

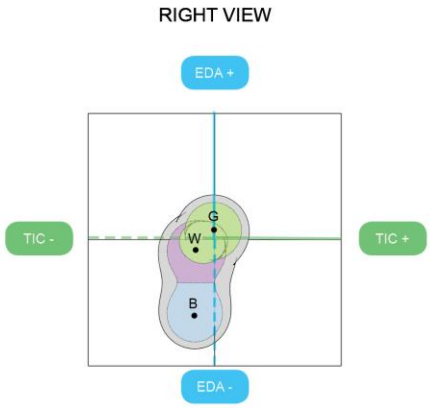


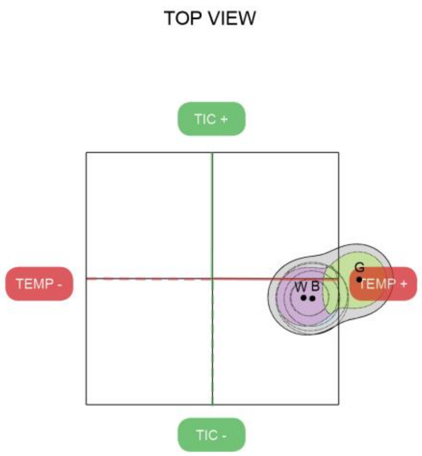
PARTICIPANT H - DAY 10				
COLOR	Q	tEDA	Temp	RPM tics
Y	VI-VIII	0.04	36.28	1.12
R	V	0.30	36.29	0.83



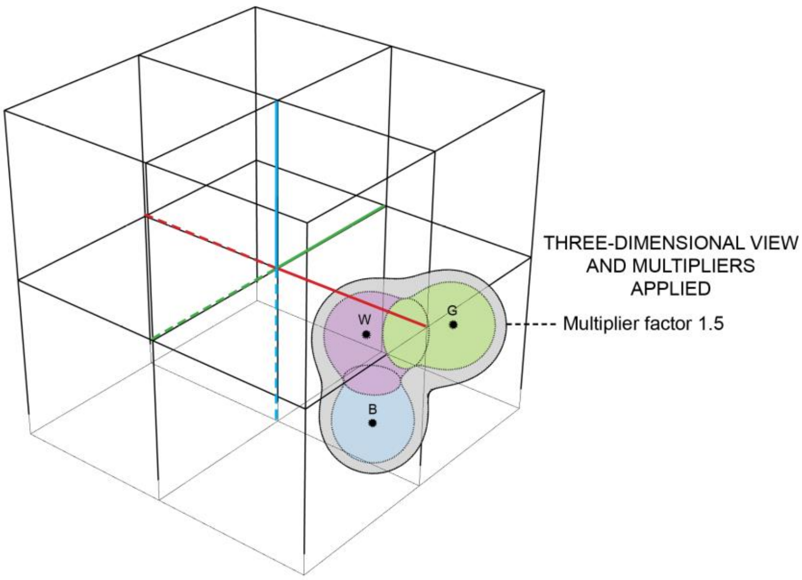
Appendix I. 3D Mood Box of Participant H on day 14





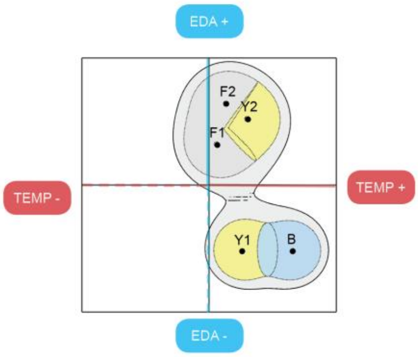


PARTICIPANT H - DAY 14				
COLOR	Q	tEDA	Temp	RPM tics
W	IV	0.14	37.41	0.42
G	I	0.18	37.96	1.14
B	IV	0.01	37.49	0.37

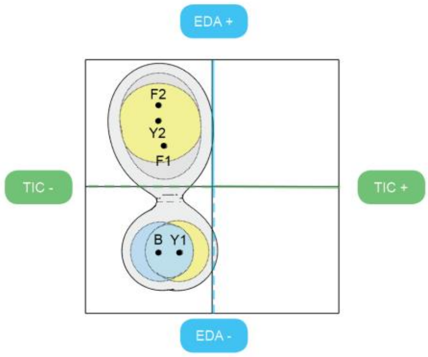


Appendix I. 3D Mood Box of Participant J on day 3

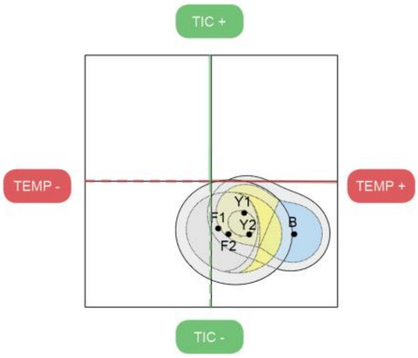
FRONT VIEW



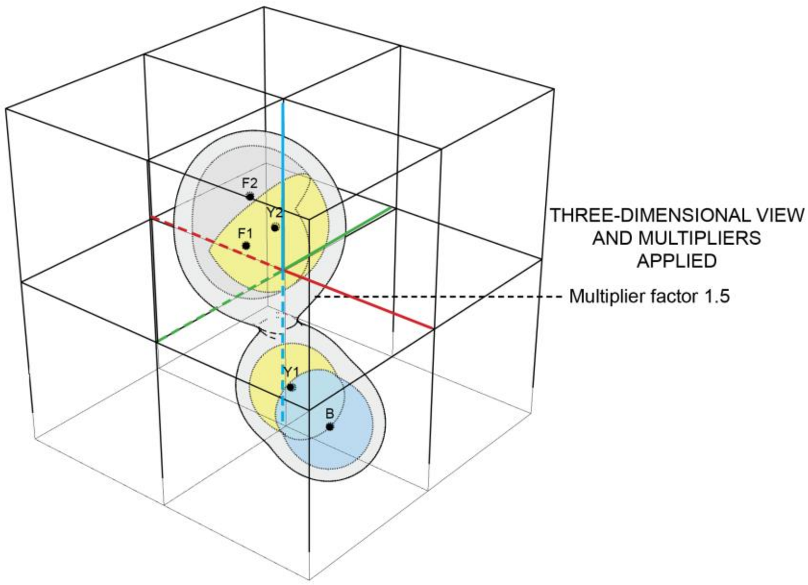
RIGHT VIEW



TOP VIEW

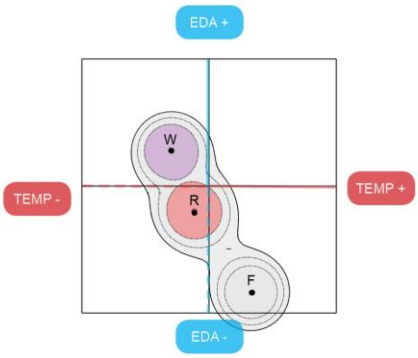


PARTICIPANT J - DAY 3				
COLOR	Q	tEDA	Temp	RPM tics
F1	III	0.41	35.95	0.22
Y1	IV	0.20	36.20	0.84
B	IV	0.20	36.70	0.00
F2	III	0.49	36.04	0.00
Y2	III	0.46	36.25	0.00

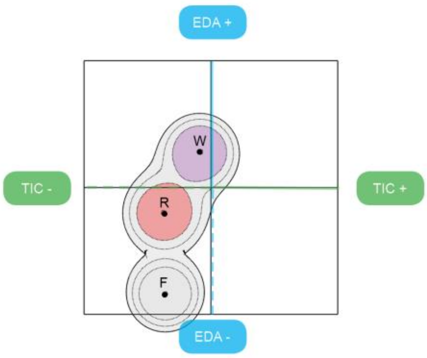


Appendix I. 3D Mood Box of Participant J on day 4

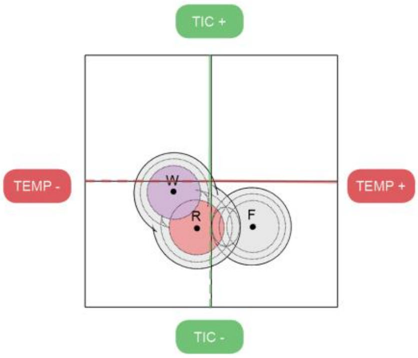
FRONT VIEW



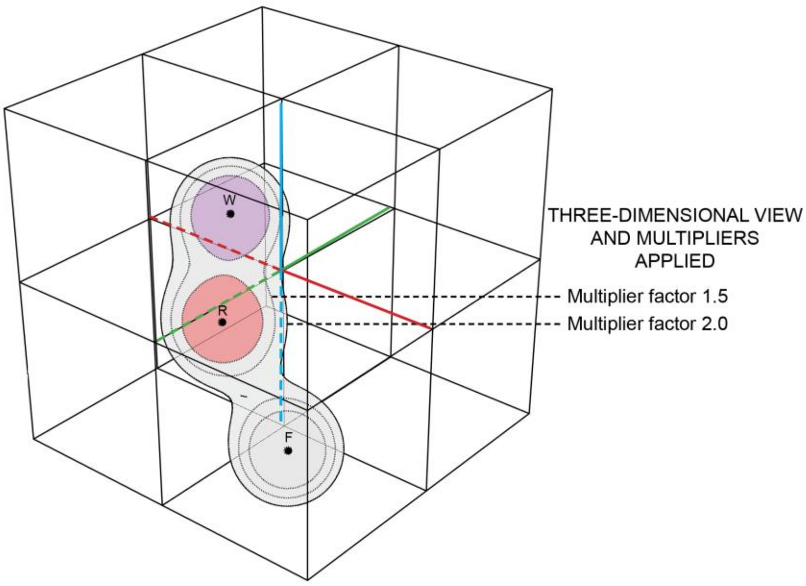
RIGHT VIEW



TOP VIEW

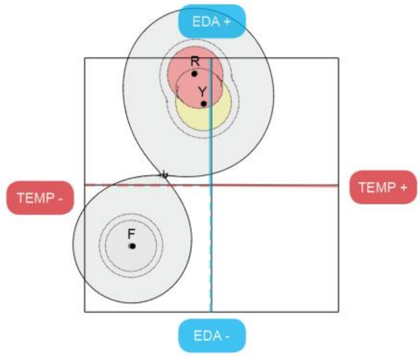


PARTICIPANT J - DAY 4				
COLOR	Q	tEDA	Temp	RPM tics
W	V	0.40	35.50	1.68
F	IV	0.12	36.29	0.30
R	VI	0.28	35.73	0.24

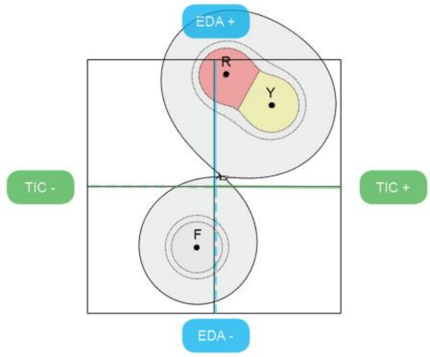


Appendix I. 3D Mood Box of Participant J on day 5

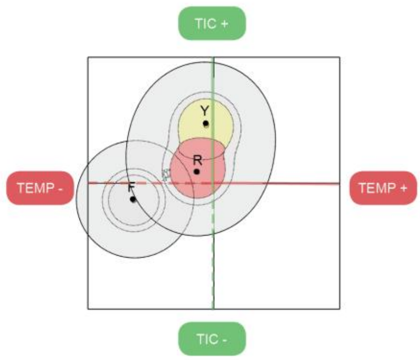
FRONT VIEW



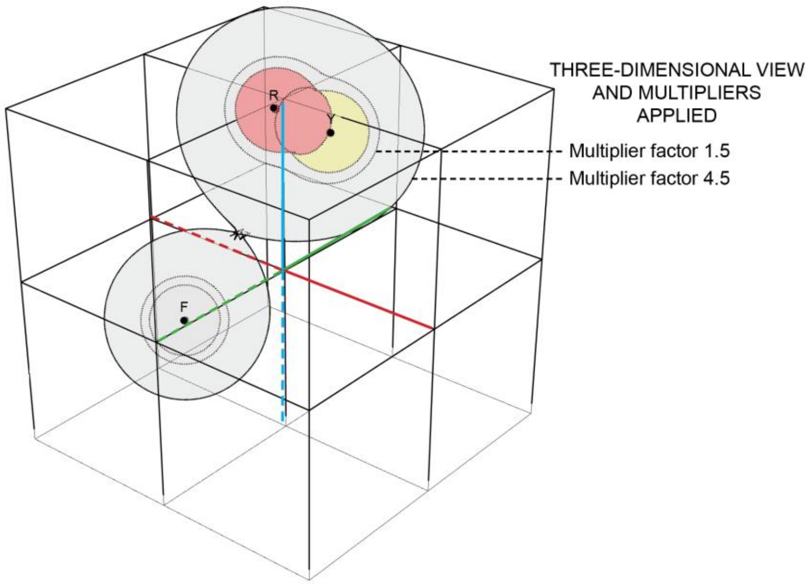
RIGHT VIEW



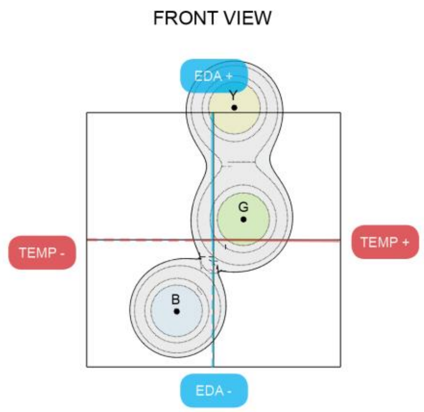
TOP VIEW

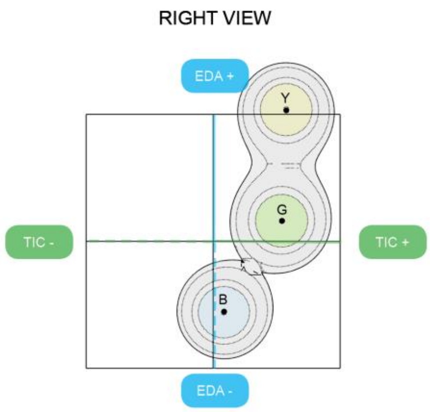


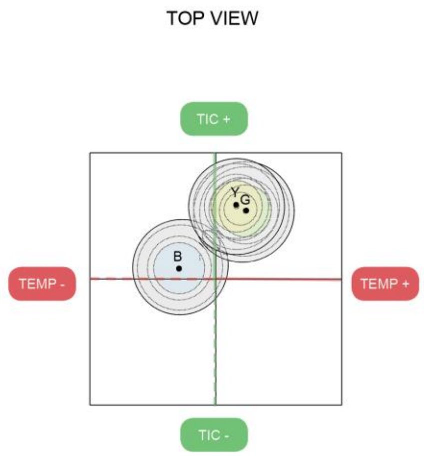
PARTICIPANT J - DAY 5				
COLOR	Q	tEDA	Temp	RPM tics
F	VI	0.21	35.08	1.42
Y	VII	0.49	35.80	4.40
R	VII	0.55	35.71	2.55



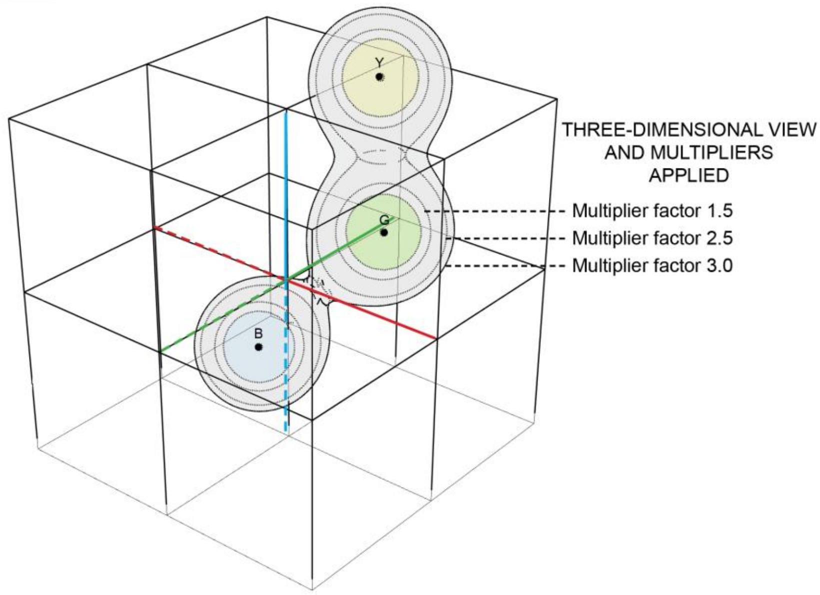
Appendix I. 3D Mood Box of Participant J on day 6





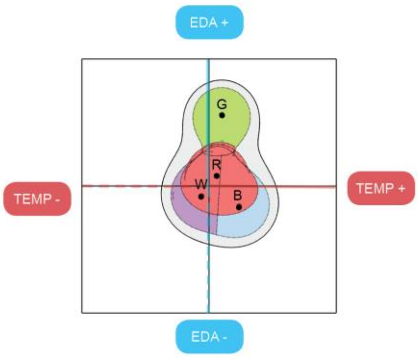


PARTICIPANT J - DAY 6				
COLOR	Q	tEDA	Temp	RPM tics
Y	I	0.59	36.08	4.98
G	I	0.37	36.17	4.80
B	VIII	0.19	35.51	2.52

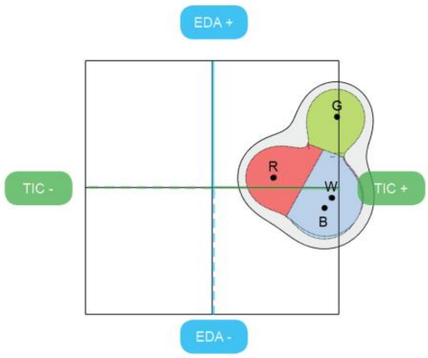


Appendix I. 3D Mood Box of Participant J on day 7

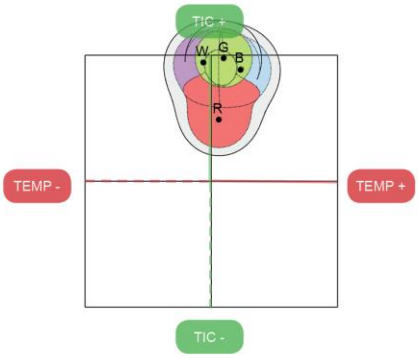
FRONT VIEW



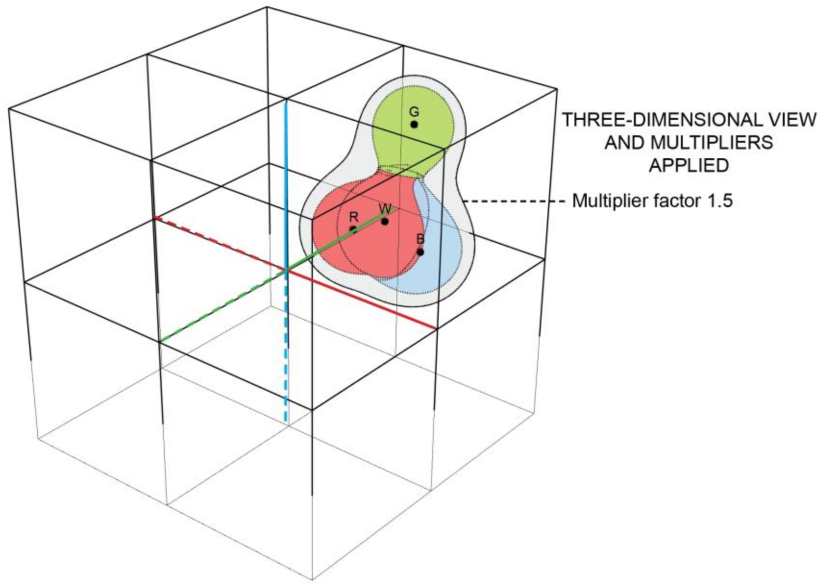
RIGHT VIEW



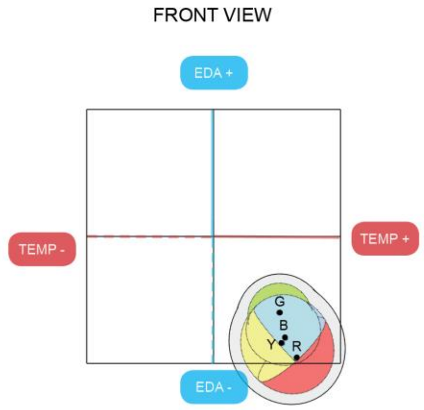
TOP VIEW

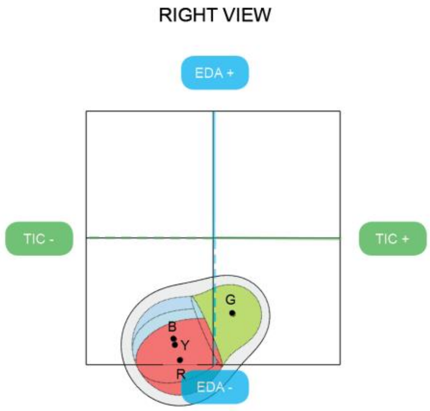


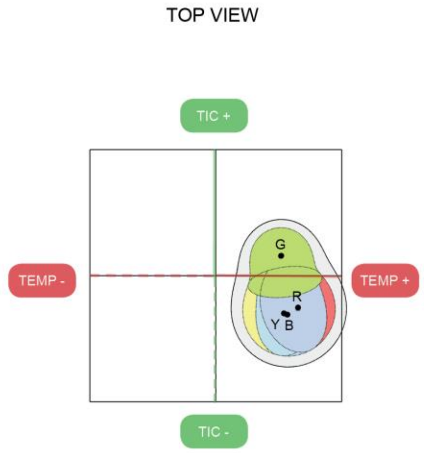
PARTICIPANT J - DAY 7				
COLOR	Q	tEDA	Temp	RPM tics
W	VIII	0.31	35.80	6.80
R	I	0.35	35.95	4.55
G	I	0.47	36.00	7.02
B	II	0.29	36.17	6.55



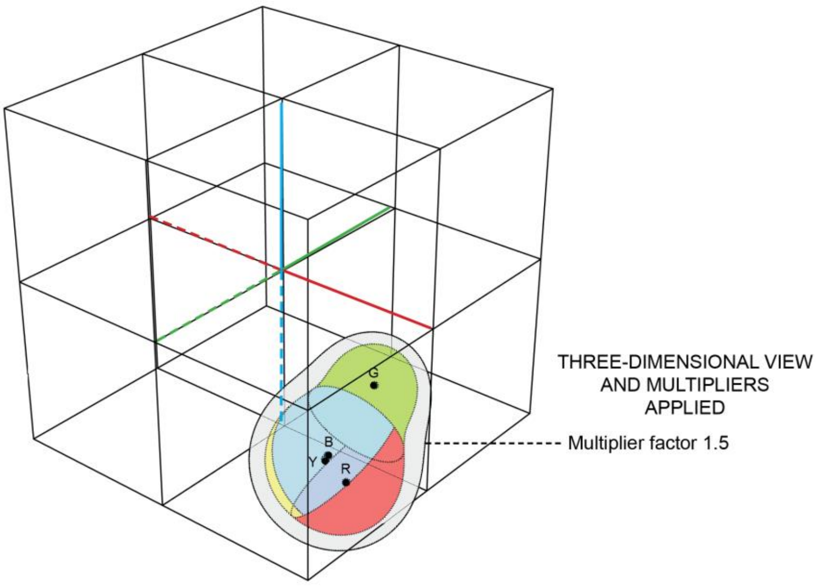
Appendix I. 3D Mood Box of Participant J on day 8



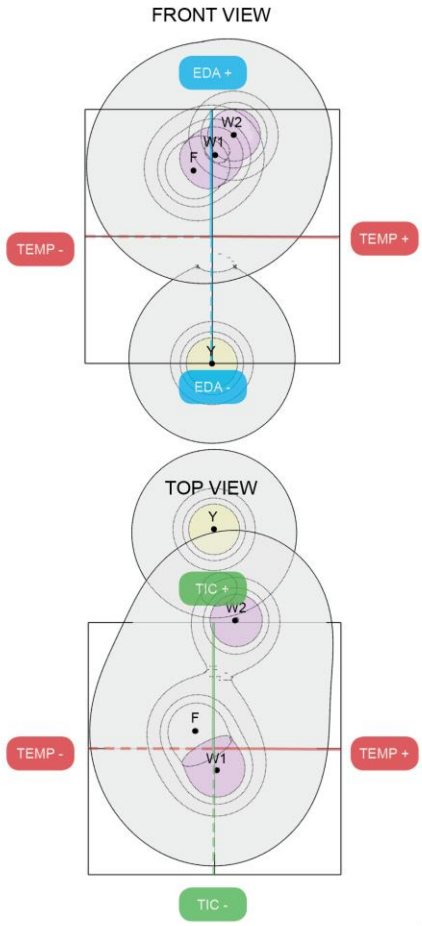


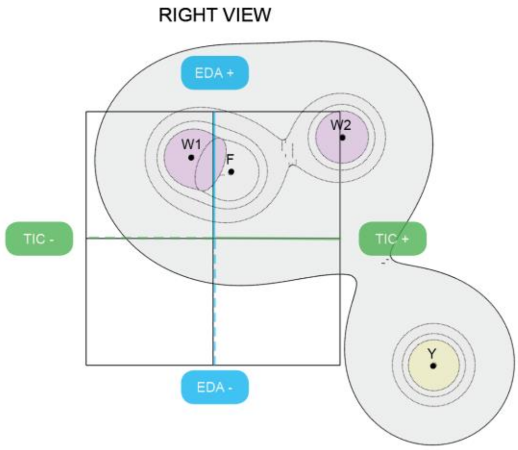


PARTICIPANT J - DAY 8				
COLOR	Q	tEDA	Temp	RPM tics
Y	IV	0.12	36.55	0.60
G	II	0.18	36.52	2.88
R	IV	0.09	36.69	0.81
B	IV	0.13	36.58	0.56

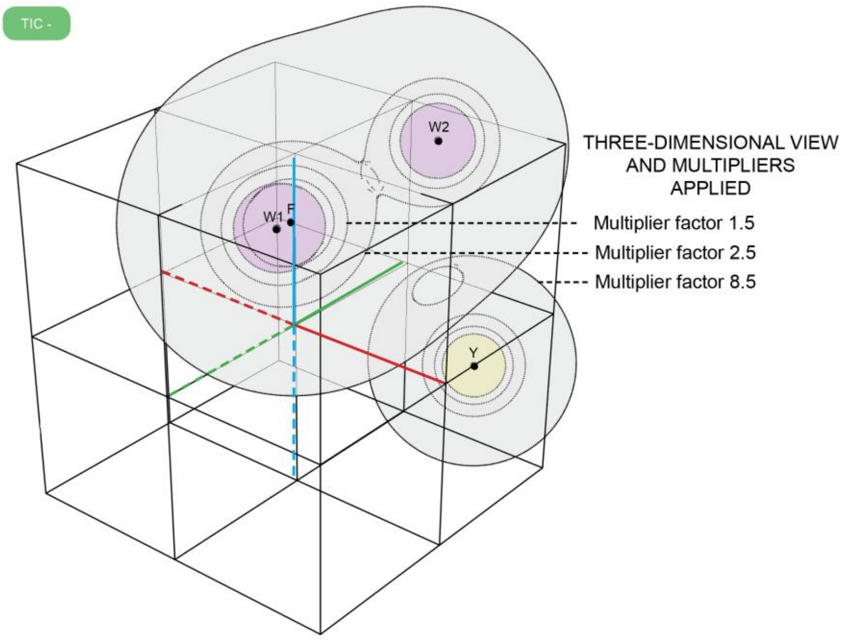


Appendix I. 3D Mood Box of Participant J on day 9

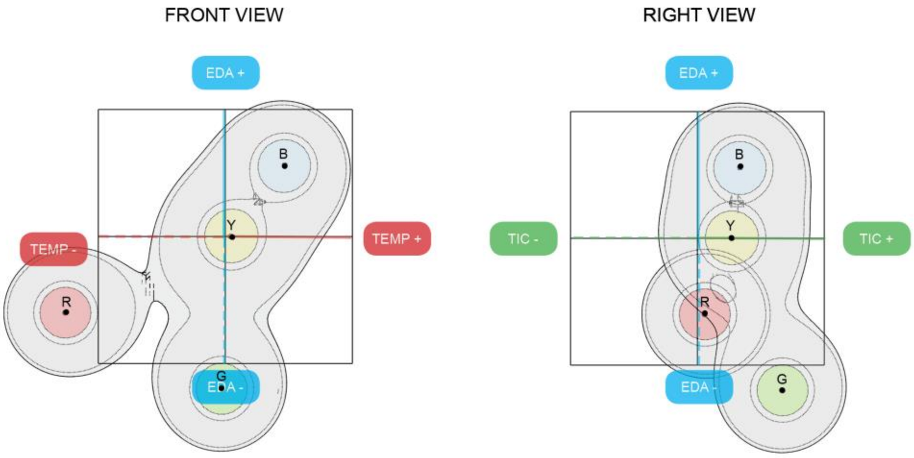


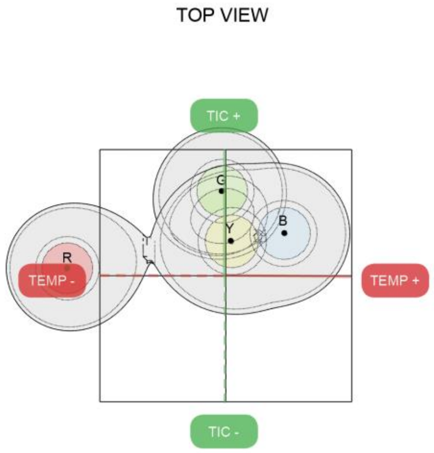


PARTICIPANT J - DAY 9				
COLOR	Q	tEDA	Temp	RPM tics
W1	III-V	0.49	35.90	1.25
F	VII	0.45	35.69	2.80
Y	II-VIII	0.08	35.87	10.80
W2	I	0.53	36.09	7.20

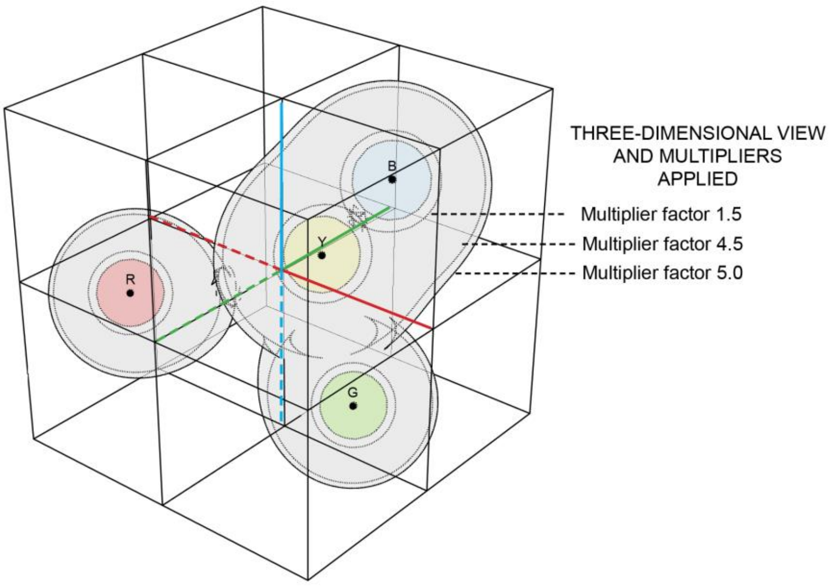


Appendix I. 3D Mood Box of Participant J on day 10

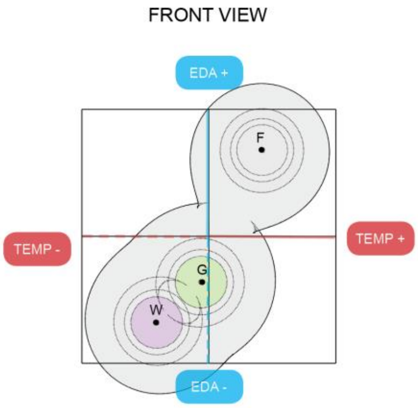


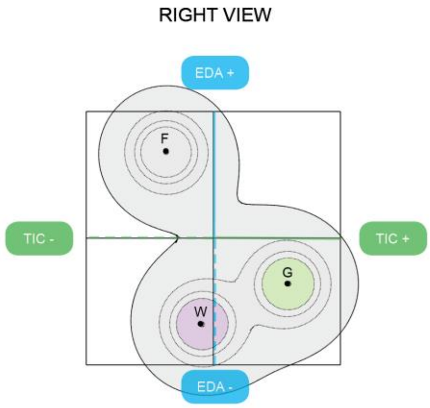


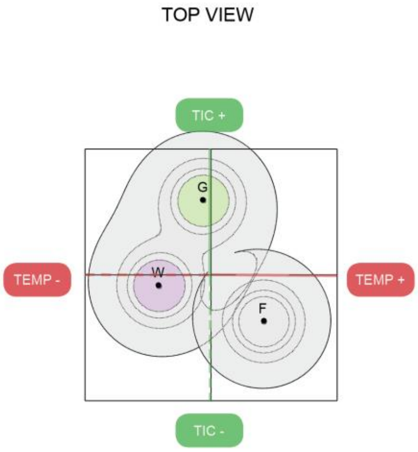
PARTICIPANT J - DAY 10				
COLOR	Q	tEDA	Temp	RPM tics
Y	I-II	0.33	35.93	3.46
G	II-VIII	0.03	35.84	5.46
R	VIII	0.18	34.30	2.39
B	I	0.47	36.46	3.78



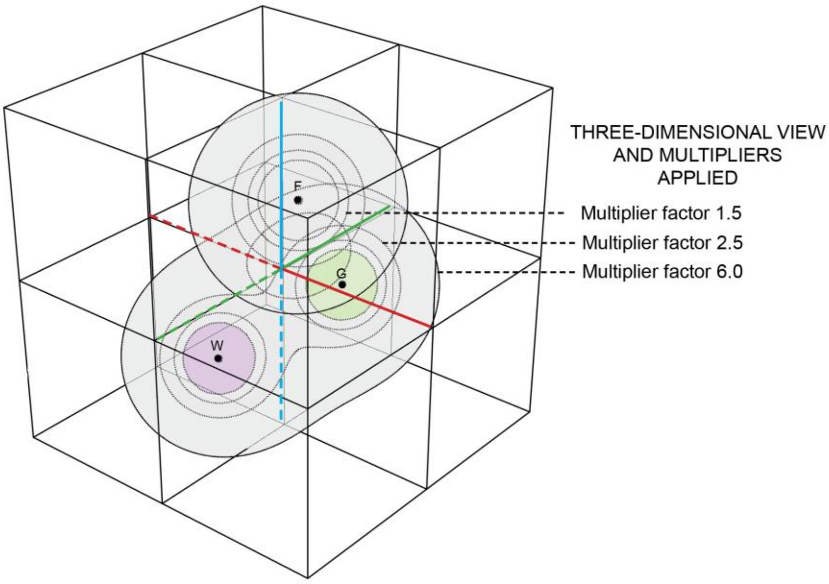
Appendix I. 3D Mood Box of Participant J on day 11



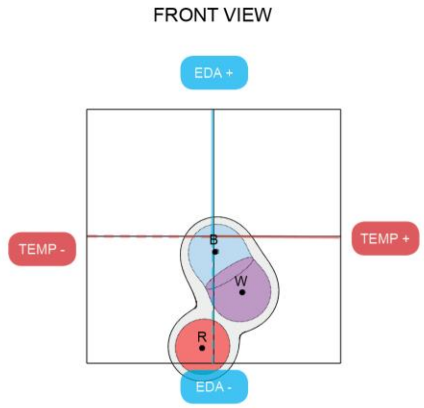


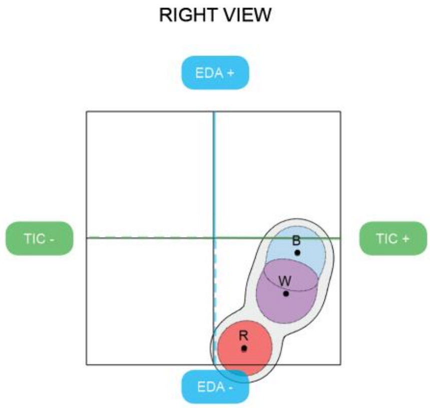


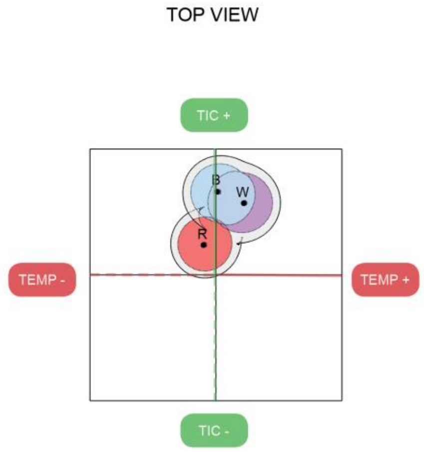
PARTICIPANT J - DAY 11				
COLOR	Q	tEDA	Temp	RPM tics
W	VI	0.16	35.36	1.65
F	III	0.50	36.40	0.24
G	VIII	0.24	35.80	5.06



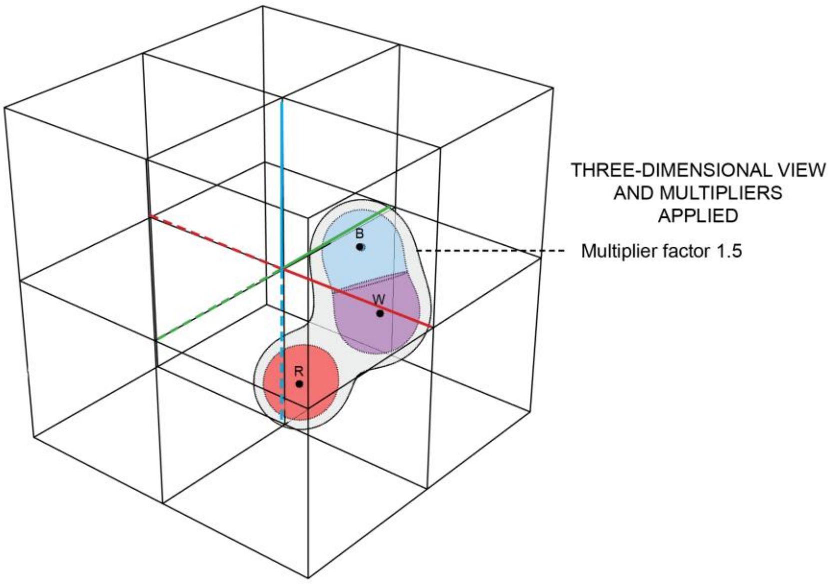
Appendix I. 3D Mood Box of Participant J on day 13



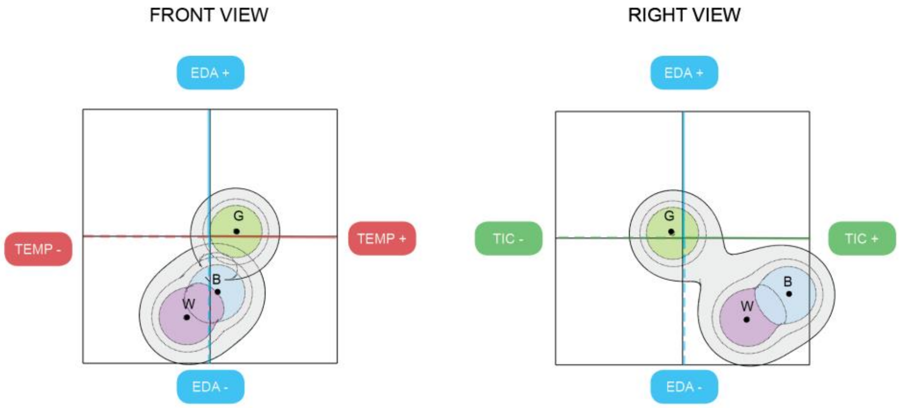


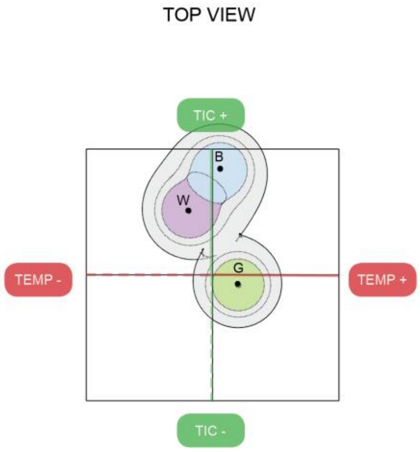


PARTICIPANT J - DAY 13				
COLOR	Q	tEDA	Temp	RPM tics
W	II	0.22	36.16	4.96
R	VIII	0.11	35.76	3.30
B	II-VIII	0.30	35.90	5.40

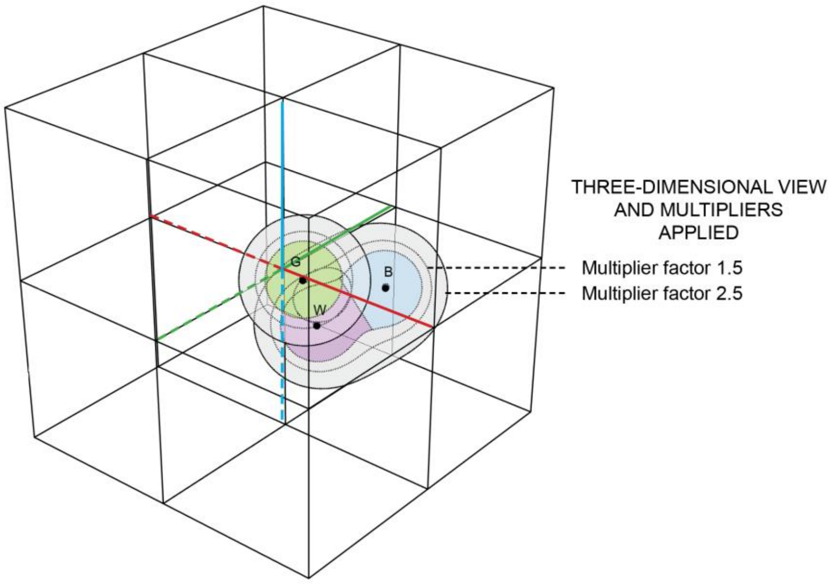


Appendix I. 3D Mood Box of Participant J on day 14





PARTICIPANT J - DAY 14				
COLOR	Q	tEDA	Temp	RPM tics
W	VIII	0.17	35.64	4.64
G	III	0.34	36.13	1.69
B	II	0.22	35.95	6.30



APPENDIX J. QUESTIONNAIRES

Participant:

Do you think s/he has any preference in colour? Yes No

If yes, which colour do you think s/he likes?

Below is a list of words that describe feelings the participant might have had. Please **CIRCLE THE ANSWER THAT BEST DESCRIBES HOW S/HE FELT IN THE VIDEO.**

Clip 1

- Do you think the participant was stressed?
  Yes
  No
  A little bit
  I don't know

  WHY?

- Do you think the participant was relaxed?
  Yes
  No
  A little bit
  I don't know

  WHY?

- Do you think the participant was excited?
  Yes
  No
  A little bit
  I don't know

  WHY?

- Do you think the participant was focused?
  Yes
  No
  A little bit
  I don't know

  WHY?

- Do you think the participant was pleased?
  Yes
  No
  A little bit
  I don't know

WHY?

- Do you think the participant was angry/upset?
  Yes
  No
  A little bit
  I don't know

  WHY?

- Do you think the participant was tired?
  Yes
  No
  A little bit
  I don't know

  WHY?

- Do you think the participant was sad?
  Yes
  No
  A little bit
  I don't know

  WHY?

- What colour do you think was on during the clip?
  ( ) White
  ( ) Fluorescent
  ( ) Yellow
  ( ) Green
  ( ) Red
  ( ) Blue