Productivity and wellbeing in the 21st century workplace: Implications of choice

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Student statement

I, Madalina-Luiza Hanc, 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.

Signature ………………………

Date …………………………….

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Abstract

The shift from industrial production to a knowledge-based economy in Western countries and internationally emphasises the growing importance of knowledge workers, i.e. highly-skilled professionals. Their productivity and wellbeing may be essential for maintaining organisational success and national prosperity. However, the role played by the workspace in achieving these outcomes is not fully established.

A gap of knowledge exists between the environmental and social sciences approaches to workspace productivity and wellbeing. The environmental sciences perspective emphasizes the role of the physical ‘workspace’ environment on productivity and wellbeing. In contrast, the social sciences approach focuses on the psychosocial processes in the ‘workplace’. Considering the physical and psychosocial determinants as independent from each other leads to an incomplete understanding of workspace productivity and wellbeing.

A global shift towards flexible working styles highlights the necessity to explore both perspectives. Aided by the development of digital work technologies, a growing number of employees are becoming able to work *anytime, anywhere*. This maximises the role of **personal choice of space and time of work** on productivity and wellbeing and may require re-examination of the role played by the physical workspace environment.

The research aims to understand both environmental and social sciences perspectives on workplace outcomes of productivity and wellbeing, particularly focussing on ‘knowledge’ work conducted in office buildings and other locations. It explores the relationship between personal choice over the space and time of work, and the quality of the physical office environment, on two outcomes: productivity and wellbeing.

The methodology adopted for this 'WorQ’, Workspace Quality and

Choice study, includes a novel tool to measure productivity using a proxy: cognitive learning. It applies the established Warwick-Edinburgh Mental Wellbeing Scale and adopts the ecological momentary assessment approach. The methodology uses short digital questionnaires and a smartphone-based cognitive testing application to assess the short- and medium-term effects of physical and psychosocial factors in the workspace.

The results show statistically significant associations with wellbeing: participants with higher levels of choice of work space and time reported higher levels of wellbeing. No clear patterns were found regarding the relationship between choice of work space and time and cognitive learning, but choice of time alone was suggested to have a potentially positive impact on learning.

The practical implications of the findings for workplace management are addressed, as is the further development of research to better understand the interactions of personal choice and the design of physical work environments.

Impact statement

‘Productivity and Wellbeing in the 21st Century Workspace: Implications of Choice’ explores the implications of personal choice over space and time of work, and of workspace quality, on the productivity and wellbeing of knowledge workers. The insights presented in this dissertation can make a positive impact in academic research and real-life workspaces.

This work is a step towards an integrated workspace theory that unites an understanding of the physical environment of workspace with that based on social sciences. Currently, these two well-established approaches generally exclude the other. Productivity and wellbeing are studied as being either short-term effects of physiological nature influenced by the internal environment within buildings, or as psychosocial processes of individuals and organisations developed over time. The methodology developed in this research explores both types of processes, revealing different effects on wellbeing and cognitive performance (considered a proxy for productivity). This research informs the current state of knowledge and highlights the benefits of cross-disciplinary approaches to workspace productivity and wellbeing research. Furthermore, the study design used in this work – which uses digital ratings and smartphone-based cognitive tests – may provide a practical starting point for researchers seeking to measure other relationships within the workspace.

This work is valuable for organisations and workspace designers, decision makers and managers concerned to ensure the productivity and wellbeing of their employees. The study design used in this work can be used for sampling employee perceptions of their workspaces – within and beyond the office building, when working ‘on the move’ – and collecting measures of cognitive performance, and of wellbeing. Such information is extremely valuable for estate and facility managers, as well as human resource professionals. As flexible working is becoming widespread nationally and globally, *choice* is an increasingly important theme with a growing number of organisations providing their employees some degree of choice over where and/or when they work. This research adopted a granular approach to measuring choice of work space and time which revealed positive, yet different effects on productivity and wellbeing. Therefore, this dissertation is particularly relevant for organisations who are considering implementing or refining their policies to maximise perceptions of personal choice of work space and time.

To make an impact across different audiences, the outputs of this dissertation will be disseminated in several ways. Articles based on this dissertation and published in peer-reviewed journals will make the findings accessible to the academic research community. Some articles may cover theoretical aspects (e.g. the development of an integrated model of the workspace as physical and psychosocial environment), others may focus on the practical aspects of the methodology (e.g. the opportunities and challenges of using smartphones in workspace research). Papers delivered at academic conferences and industry-led events[1] will also provide platforms for public engagement.

[1] Workspace-focused events may include those organized by Corenet Global, British Council for Offices, International Facility Management Association (IFMA, e.g. 'World Workplace' conferences), Institute of Workplace and Facilities Management (formerly the British Institute of Facilities Management, BIFM), Royal Institute for Chartered Surveyors (RICS).

Abbreviations

ABW - Activity-based working

AHT - Average handling time

AI – Artificial intelligence

AL - Artificial light

AQ - Air quality

BAB – ‘Babble Bots’ cognitive test

BCO - British Council for Offices

BUS - Building Use Studies

CBE - Center for the Built Environment, Berkeley, University of California

CIPD - Chartered Institute of Personnel and Development

CRE - Commercial Real Estate

DA - Design and aesthetics

DHR - Daily history record

EEG - Electroencephalograph

EMA - Ecological momentary assessment method

ESM - Experience sampling method

EU – European Union

F - Female participants

FM - Facilities Managers

FS - Flourishing Scale

GBE - Great Brain Experiment

GDP - Gross Domestic Product

GEM - Game-based learning evaluation model

HDI - Human Development Index

HR - Human Resources

HRV - Heart rate variation

HSE - Health Survey for England

IAQ - Indoor air quality

ICT - Information and communication technologies

IEQ - Indoor Environmental Quality

IFMA - International Facility Managers Associations

LEED - Leadership in Energy and Environmental Design

M - Male participants

NA - Negative affect

NL - Natural light

NO - Noise

OB - Office building

OCB - Organizational citizenship behaviour

OECD - Organisation for Economic Co-operation and Development

OED - Oxford English Dictionary

ONS - Office for National Statistics

OPO - Open plan office

PA - Positive affect

PANAS - Positive And Negative Affect Schedule

PFC - Prefrontal cortex

POE - Post occupancy evaluation

PR - Privacy

RBS - Royal Bank of Scotland

RIBA - Royal Institute of British Architects

SBS - Sick Building Syndrome

SCT - Social Cognitive Theory

SDT - Self-Determination Theory

SM - Scientific Management

SPL - Sound Pressure Level of speech

STI - Speech Transmission Index

SWLS - Satisfaction with Life Scale

SWEMWBS - Short version of the Warwick-Edinburgh Mental Wellbeing Scale

TCR – ‘True Color’ cognitive test

TE - Temperature

TUN – ‘Tunnel Trance’ cognitive test

UCL - University College London

UF - Usability of furniture

UK - United Kingdom of Great Britain and Ireland

UNDP - United Nations Development Program

UNI - ‘Unique’ cognitive test

UNICEF - United Nations Children’s Fund

US - United States of America

WEMWBS - Warwick-Edinburgh Mental Wellbeing Scale

WFQ - Word frequency queries

WGBC - World Green Building Council

WHO - World Health Organization

WorQ – ‘Workspace Quality and Choice’ study

WSSE - Workplace social self-efficacy
WT - WiFi, IT, and work technologies

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Chapter 1. Introduction

1.1. The context of this work

'*What drives productivity and wellbeing*[2] *in the workplace?*' may be one of the most important questions emerging since the Industrial Revolution, when technological changes relocated production processes from homes to factories. It is a question that interests organisations and professionals involved in the planning, designing, and management of work *places* – such as the four organisations who jointly sponsored this doctoral research – and all those interested in the future of work. This question is frequently re-examined, producing new answers as technology and society as a whole – including the workers' role in society – change.

This thesis seeks to understand the relationship between choice over the space and time of work, productivity and wellbeing, and the role of the physical workspace in this relationship. It is applicable to *knowledge workers*, professionals working in cognitively demanding jobs, whose work does not typically produce quantifiable outputs. The current section introduces the context of this work by presenting a high-level summary of the key constructs and paradigms that informed this approach.

(A) WORK, THE ECONOMY AND OFFICE BUILDINGS

People are the most important resource of any country, industry or organisation. Their health, wellbeing and development should be at the forefront of every policy agenda (International Labour Organization (ILO), 2019). While health and wellbeing may have multiple determinants (as will be shown in

[2] The terms 'wellbeing' and 'well-being' are used interchangeably in the literature. This research adopts the former spelling.

chapter 2), it is certain that **work plays a central role in most people's lives**. The majority of the 7.6 billion people living on our planet are working: 3.3 billion women and men out of the 5.7 billion of working age (ILO, 2019), which means that 58% of those who can work, do. Across most member countries of the Organisation for Economic Co-operation and Development (OECD), employment rates in 2018 were above those recorded before the global 2007-2008 financial crisis (OECD, 2018a). In the UK, employment rate was estimated at 76.1% in 2019 – the highest figure on record, according to Office for National Statistics (ONS, 2019b).

The services sector is the key driver of economic growth – and the main employer – in countries with strong economic performance. Across the 'group of seven' countries with the most advanced economies ('G7') - Canada, Japan, France, Italy, Germany, United Kingdom (UK), and the United States (US) - services accounted for 77% of employment in 2017 (OECD, 2018b). In the 28 countries of the European Union (EU), this percentage was 72 (OECD, 2018b). In the UK, 83% of workforce jobs were in the services sector in 2018 (ONS, 2019a). **National productivity and the proportion of office-type jobs are associated**: as countries develop, office-based employment and the demand for office buildings are growing (Marmot, 2016).

A growing proportion of the services-driven economy is comprised of **knowledge workers**: managers, senior officials or professionals involved in fast-paced, cognitively demanding activities orientated towards quality. In most cases, their work does not typically produce quantifiable outputs, therefore a proxy metric must be used to assess their productivity. Moreover, supported by developments in information and communication technologies (ICT) and digital work tools, they are able – or required - to switch between different work spaces and time schedules. **The effects of personal choice over space and time of**

work on their productivity and wellbeing are not yet known.

Buildings and workplaces have clear implications on the health and wellbeing of people and are associated with their productivity. **The vast majority of business operating costs are incurred by employee salaries**, benefits and equipment: 85% in the UK (Morell, 2003; Ramidus, 2016) or 90% in the US (World Green Building Council (WGBC), 2014). Even a small improvement in the health and wellbeing of employees is therefore associated with important financial gains derived from productivity increase, and reduction of illness-related absenteeism or presenteeism (Clements-Croome et al., 2015).

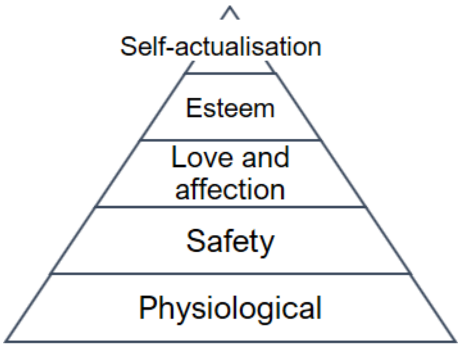
(B) PHYSIOLOGICAL AND PSYCHOSOCIAL NEEDS IN THE WORKPLACE

Organizations active in the research, development, and promotion of best practices in the built environment have demonstrated a growing interest in the relationship between buildings and occupant health and wellbeing in recent decades. Some of the sources cited in this work (chapter 2) focus on sustainability within the built environment, such as the UK Green Building Council (UKGBC) or its parent network WGBC, while others are professional body organisations such as British Council for Offices (BCO) or Royal Institute of British Architects (RIBA). Their approach focuses on the **quality of the built environment as supporter of health**. Other perspectives on workplace health and wellbeing – originating from organisations interested in the future of work such as ILO or OECD – illustrate a different paradigm. These show concerns towards employers' ability to offer 'fair' and 'decent' working conditions that meet employees' **psychological and social needs**.

The relationship between employee health, wellbeing, and productivity in the workplace could be explained by referencing to Abraham Maslow's theory of human motivation (Maslow, 1943). According to this broadly influential perspective, any behaviour that involves motivation “must be understood to be a channel through which many basic needs may be simultaneously expressed or satisfied. Typically an act has *more* than one motivation” (: 370). Maslow distinguished between five psychological needs that are ordered hierarchically. The lowest level in figure 1-1 shows a structure of needs, starting with ‘basic’ physiological drives, such as hunger, thirst or need for recovery, and continuing upwards towards ‘higher’ levels of motivations. Upper strata of needs only emerge after the lower ones are being gratified. The need for self-actualisation – the highest of the needs – is perhaps the strongest motivator of productive work:

> “This tendency might be phrased as the desire to become more and more what one is, to become everything that one is capable of becoming” (: 382)

Figure 1-1 Maslow's theory of human motivation: The hierarchy of psychological needs. Based on Maslow (1943)



Several high-impact initiatives have been developed based on evidence derived from medical and behavioural sciences relevant to health, wellbeing and productivity in the built environment. Examples include two complex building evaluation frameworks developed in the US - WELL® Building Standard (Delos Living, 2018) and the Fitwel® Rating System (Center for Active Design, 2018) - and BCO’s comprehensive investigation entitled ‘*Wellness Matters*’ (BCO, 2018). Such initiatives – reviewed in chapter 2, section 2.1.4. – focus primarily (although not exclusively) on the importance of the physical qualities of the workplace in supporting occupant health and wellbeing. Parameters of interest – which are also widely researched in the 'environmental sciences' branch of academic literature, as shown in section 2.3 – include temperature, air quality, noise, or light and lighting. Reflecting on these parameters from Maslow's perspective (figure 1-1), **these parameters refer to basic physiological needs that affect health and comfort** – being thermally comfortable, breathing clean air, etc. – but the upper ones are allocates far less importance.

The physical qualities of the built environment are not the only aspect in the workplace that influences health, wellbeing, and productivity. The question '*What makes a good workplace*?' - i.e. one where employees are happy and productive - is answered differently in psychology, sociology, management, or human resources literature ('social sciences'). The Great Place to Work Institute® (2019a), which researches best practices in workplace management – and offers recognition to companies who implement them – adopts an employee-centric answer:

> "A great workplace is one where people[3]:
> 1. Feel valued and trusted
> 2. Have a sense of purpose - that what they do is not 'just a job'
> 3. Are proud of what they do and who they work for
> 4. Have opportunities to develop personally and professionally
> 5. Are encouraged to balance their work and their personal lives - they feel able to put their needs ahead of those of the business
> 6. Are committed to doing their best and enjoy working with their colleagues to deliver the organisation's goals
> 7. Are more customer focused and brand ambassadors of

[3] The original list is bullet pointed – numbers have been added here for ease of reference.

the business.” (Great Place to Work Institute®, 2019b)

This conceptual model of a ‘great’ workplace highlights several psychological needs described by Maslow: esteem (points 1,3), self-actualization (points 2, 4, and 6), or love/belonging (points 5, 6), safety (point 5). No importance is given, however, to any of the basic needs – or the physical settings of the workplace.

Recent initiatives from intergovernmental agency ILO also reflect a concern for creating a workforce that fulfils the higher psychological needs in Maslow’s theory. In January 2019, ILO’s *Global Commission on the Future of Work* turned to governments and employers worldwide to commit to a “human-centred agenda needed for a decent future of work” (ILO, 2019a). The landmark report entitled ‘*Work for a brighter future’* (ILO, 2019b) includes ten key recommendations that address the need to increase investment in “people’s capabilities” and wellbeing (: 2), and in “decent and sustainable work” (: 4).

As shown above, **managerial dimensions** of the workplace are essential to health, wellbeing, and productivity, as they allow for the gratification of the higher levels in Maslow’s hierarchy of needs (figure 1-1). Several different theories from psychology, sociology, and cognitive science (reviewed in section 2.4.) propose that ***choice, control,* and *autonomy* - at work and in life - are essential in motivating human development including wellbeing, performance, social and cognitive development and learning**.

(C) CHANGES IN THE WORLD OF WORK: THE IMPORTANCE OF SKILLS AND LEARNING

In recent decades, important advances in physical and digital technologies, data analytics and computing and artificial intelligence have transformed most aspects of life in an increasingly globalized world (Cotteleer and Sniderman, 2017). Technological progress has decisively permeated the world of work as advances in information and communication technologies (ICT) have transformed *where, when* and *how* work is performed. However, this phenomenon acts as an opportunity for the highly skilled, and as a threat to low or middle-skilled segments of the workforce. According to OECD's *Employment Outlook* reports the workforce has been experiencing "occupational polarisation during recent decades – that is, a decline in the share of total employment attributable to middle-skill/middle-pay jobs, which has been offset by increases in the shares of both high- and low-skill jobs" (OECD, 2017b: 10). ILO's '*Work for a brighter future*' report cited in the previous section predicts that this trend will only be accentuated:

> "Technological advances – artificial intelligence, automation and robotics – will create new jobs, but those who lose their jobs in this transition may be the least equipped to seize the new opportunities. Today's skills will not match the jobs of tomorrow and newly acquired skills may quickly become obsolete." (ILO, 2019b: 1).

To cope with these pressures and retain employability in the future, **the acquisition of occupational skills – i.e. learning - will be essential**: "routine tasks and skill intensity are key determinants of the substitutability of capital for labour" (OECD, 2018a: 64). The ILO calls on employers and governments to enhance opportunities for "lifelong learning that enables people to acquire skills and to reskill and upskill" (ILO, 2019b: 2).

(D) SUMMARY

In summary, the context of this work is characterised by the following key paradigms:

1. As work technologies – and work itself – are changing, the role of the workspace and of personal choice on the growing number of knowledge workers requires examination. Exposure to different spatial and environmental

characteristics may lead to different effects on the concentration and productivity of the employees. At the same time, ***personal choice* over space and time of work** may have short, medium and long-term effects on the psychosocial mechanisms supporting personal development and wellbeing and learning.

2. The question '*What drives productivity and wellbeing in the workspace?*' is answered using different constructs, depending on how the workplace is conceptualised as a physical space, or psychosocial environment. This work, however, addresses this knowledge gap by conceptualising the **workspace as both a physical and psychosocial environment**.

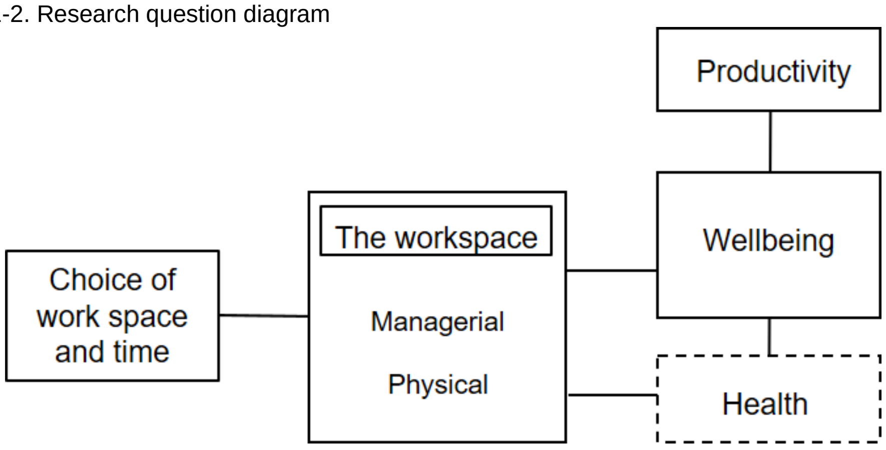
3. Finally, as knowledge work productivity cannot be measured using quantitative approaches, a proxy metric is required. Given the growing importance of skill acquisition and learning (as shown by ILO and OECD), this thesis uses **cognitive learning as a proxy for knowledge worker productivity**.

1.2. Research question and objectives

This thesis adopts an interdisciplinary approach intended to answer the following research question:

Does choice of work space and time affect productivity and wellbeing? What role does the workspace play in this relationship?

Figure 1-2. Research question diagram



The research has the following key objectives:

Objective 1	To assess the effect of choice of work space and time on productivity, conceptualised as cognitive learning.
Objective 2	To assess the mediating effect of the workspace on the relationship between choice of work space and time and productivity, conceptualised cognitive learning.
Objective 3	To assess the effect of choice of work space and time on wellbeing.
Objective 4	To assess the mediating effect of the workspace on the relationship between choice of work space and time and wellbeing.
Objective 5	To explore workers' perceptions of what elements in the workspace support - and detract from – the ability to work productively.

Several observations should be made regarding the assumed causal path of the theoretical model in figure 1-2, which was derived from the literature briefly introduced in this chapter and fully reviewed in chapter 2.

Firstly, choice of work space and time, the independent variable, is hypothesised to be associated with the productivity and wellbeing dependent variables. As will be shown in section 2.5., choice, control, and autonomy are widely believed to activate motivational and affective processes associated to cognitive and social development, performance, and wellbeing. This study aims to understand if this particular type of exercising choice – may have similar effects. Research from Gensler (2019) conducted on over 6,000 workplace users in the US found that 71% of people who had choice in where to work reported "a great workplace experience" (: 14).

Secondly, there is a relationship between the two outcome variables: the model assumes that health and wellbeing are precursors – or 'roots' – of the productivity outcome. However, this research explores productivity and wellbeing as distinct outcomes without explicitly measuring physical health, hence the use of the dotted line in figure 1-1.

Thirdly, the workplace is conceptualised as being a physical and psychosocial environment that mediates processes associated with the two outcomes:

- Physiological responses to environmental or spatial stimuli within the workplace that impact on physical and mental health, and concentration.
- Psychological and social responses to managerial dimensions within the workspace that affect wellbeing.

Choice is hypothesised to affect both types of processes. By exercising choice over space and time of work, employees would be able to limit – or enhance - their exposure to both physical or psychosocial factors in the workplace that are conducive to productivity or wellbeing. They could choose spaces better suited to their different work requirements, moods or preferences – for example avoid noisy areas when they need to concentrate on focused work, or seek out open spaces when collaboration is required.

1.3. Potential value of this work

This work aims to gather detailed observations of employee choice of work space and time, a phenomenon gaining momentum nationally and globally. Research and initiatives from governmental, professional or intergovernmental bodies suggest a growing belief that choice of work space *or* choice of work time are beneficial, however this work aims to explores them simultaneously. Choice and autonomy may be particularly valuable for knowledge workers who need to manage themselves. In the UK, a country where knowledge workers make up the majority of the workforce (approximately 60% according to Brinkley *et al.*, 2009), the scope of this dissertation may be particularly significant.

Potentially the results of this work will allow workplace decision-makers to re-evaluate their workplace utilization or flexible working policies in ways that attract benefits for their organisations and employees alike. If choice is found to be associated with productivity, implementing policies that enhance personal choice would lead to financial gains from productivity increases. If choice is found to affect wellbeing, gains could also be attained from reduction of absenteeism and presenteeism. Other benefits deriving from potential associations between choice and the dependent variables may refer to talent acquisition and retention, if choice is associated with additional behavioural or affective outcomes, such as workplace satisfaction or engagement.

For these reasons, an investigation of the effects of choice of work space and time on productivity and wellbeing in the context of knowledge work may be a worthwhile and timely pursuit.

1.4. Dissertation outline

Chapter 2 reviews the literature related to workspace productivity and wellbeing. This includes a systematic review of evidence-based articles published in the recent decade, and a review of several robust scales used to measure wellbeing. The chapter highlights a knowledge gap identified in the literature.

Chapter 3 presents the methodology developed for gathering empirical evidence to answer the research question, based on a review of relevant methodologies, pilot testing and revisions. The chapter presents the outline of the Workspace Choice and Quality study (‘WorQ’) and data analysis strategies.

Chapter 4 presents the results of the WorQ study, obtained from a sample of UK-based office workers. These findings are discussed in **chapter 5**, which also reflects on the implications of the findings, acknowledges their limitations and recommends directions for future research.

Chapter 6 concludes the dissertation by reflecting on the insights revealed by every stage of the research.

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Chapter 2. Productivity and wellbeing in the 21st century office: Literature review

The previous chapter summarised the reasons that the effects of choice of work space and time on productivity and wellbeing is an important and timely research topic. It also introduced the key factors and relationships studied by this research. The following chapter evaluates the current state of knowledge in the field, revealed from the review of relevant workspace productivity and wellbeing literature. While most of the sources cited in the next sections are research articles published in peer-reviewed journals, additional sources considered reliable are also consulted, such as research from intergovernmental or governmental agencies, or professional organisations. While these sources sometimes include anecdotal evidence that may not necessarily fulfil the rigour criteria of academic research, the concerns they reflect are considered to have some relevance for this work.

This chapter presents key background information, especially statistics on the global and national workforce, predominant sectors and job types, where (and when) work is performed. Wherever possible, international figures are presented, however the UK background is cited as a useful baseline reference, and as the country where this research was conducted.

The chapter also provides a detailed review of the current state of knowledge in the field of workspace productivity and wellbeing:

- Approaches to measuring workspace productivity and wellbeing, as shown by a systematic review of evidence-based academic literature published in peer-reviewed journals in the last decade.
- Conceptual approaches to wellbeing in general and in relation to the workspace, as shown by a review of academic literature.

2.1. Importance of workspace productivity and wellbeing research

This section presents the key reasons why the measurement of workspace productivity and wellbeing for knowledge workers may be worthwhile and timely pursuits for organisations and professionals interested in the future of work and the workspace. These include:

- Relationships between productivity and wellbeing, national and organisational growth.
- The scale of this relationship, globally and in the UK (table 2.1):
    - How many people are in work; key industries;
    - The role of office workspaces;
    - The importance of knowledge workers;
- Development of flexible working and relation to knowledge work.

Table 2-1. Work, office workspaces and knowledge workers: World and the UK

Statistic	Area	UK
People of working age in work	World: 58%	76%
Services as percent of workforce	World: 49% G7: 77% European Union: 72%	83%
Office-type jobs as percent of workforce	13% - 66% (44 countries only)	58%
Knowledge workers as percent of workforce	Unknown	60% - 70%
Flexible working as percent of workforce	European Union (28 countries): 17% US: 20%	14% home working

References: (ILO, 2018, 2019). ONS (2014, 2019a, 2019c), OECD (2018b, 2019a), Marmot, (2016), Oseland et al., (2011), Brinkley et al. (2009), Eurofound (2017)

2.1.1. Productivity and wellbeing: Definitions and implications for national growth

According to the OECD (2001), **productivity is a key driver of economic growth and performance**. Common productivity metrics at the national level adopt the Gross Domestic Product (GDP) output measure, which quantifies the total expenditure on goods and services minus imports, and input measures of capital, labour and other factors. GDP per capita and GDP per hour worked are frequently used to assess labour productivity, however:

> “Labour productivity only partially reflects the productivity of labour in terms of the personal capacities of workers or the intensity of their effort”. (OECD, 2001)

A key limitation of GDP-based metrics is that they require straightforward production processes which lead to clear and quantifiable outputs. In recent decades, international institutions such as the United Nations Development Program (UNDP) or OECD have addressed the **limitations of using GDP as an indicator of human development** or social progress. The Human Development Index (HDI) was created by the UNDP in 1990 as “a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living” (UNDP, no date). These aspects closely resemble the World Health Organization (WHO) definition of wellbeing as mental health:

> “a state of well-being in which every individual realizes his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community” (WHO, 2014).

The WHO definition suggests that wellbeing is a necessary ingredient of productivity. Therefore, it can be argued that while productivity is a measure of economic growth, wellbeing - as an indicator of human development - may be a *precursor* of productivity.

2.1.2. People in work and economic drivers: World and the UK

Globally, the majority of the working age population currently participate in the labour market: 58%, or 3.3 billion people (ILO, 2019). Employment performance is back to the levels before the financial crisis on 2007-2008

(OECD, 2018a). However, this proportion varies across the globe and is associated with specific industries.

In recent years, the UK labour market has been characterised by "strong performance" (Taylor, 2017: 17), with exceptionally high employment rates. Estimates from the Labour Force Survey from October to December 2018 revealed that 32.6 million people were in work in the UK as shown by the Office for National Statistics (ONS, 2019c). This represents 76.1% of the population of working age (16 to 64).

Across the globe, employment is driven by services (49%), agriculture (28%) and industry (23%) (ILO, 2018). However, this ratio is significantly different among the world's strongest performing economies, where the services sector is the key driver and employer. Services accounted for "about 35 to 50% of total value added and total employment across OECD countries" in 2015 (OECD, 2017a: 60) . The share is considerably higher in the seven most advanced economies or 'G7' (77% of employment in 2017) (OECD, 2018b) and countries such as the UK where is it 83% (ONS, 2019a).

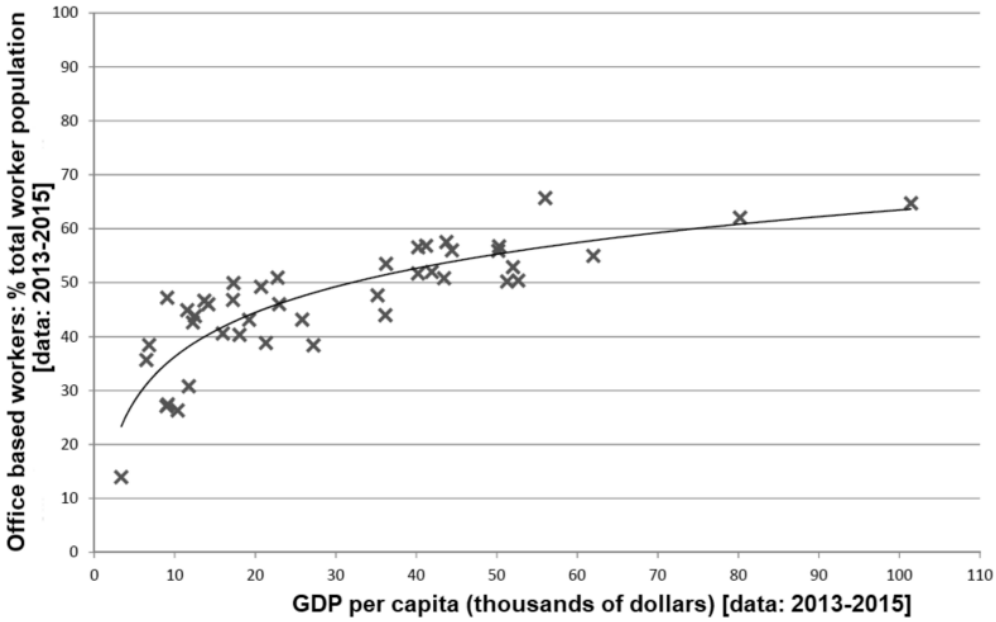
2.1.3. Office workers and office space demand

No data are available on the total area of office space across the world, or exact number of office workers, however estimates of the percent of office workers from total employment can be made based on occupations likely to require office settings. A recent analysis of global workplace trends estimated the national percentages of office workers in 44 countries[4] between 2013-2015, by including "managers, professionals, technicians and associate professionals and clerical support workers" (Marmot, 2016: 23). **Office workers represent around**

[4] The analysis includes data from 44 countries in 2013-2015 and excludes large population countries such as China or India, for which reliable data were not available.

two thirds of employees in countries like Luxembourg and Switzerland, and over a half in the United States, the UK and most Western European countries. As countries grow and become wealthier, “the proportion of their workforce that is comprised of office workers increases” (Marmot, 2016: 24). As shown in figure 2-1 below, GDP per capita is associated with the share of office workers as a percentage of the total working population.

Figure 2-1. GDP per capita and percentage of office workers. (Marmot, 2016: 23)



While the office market is not homogenous, data from the largest Commercial Real Estate (CRE) services companies show that, after recovering from the 2008 financial crisis, **global office space demand is generally on an upward trend** (CBRE, 2017; Colliers International, 2017a, 2017b; Cushman & Wakefield, 2017a; JLL, 2017). Office space demand is high in the UK, particularly London which, at an average cost of $22,665 per workstation in 2017, is the second most expensive market in the world after Hong Kong (Cushman & Wakefield, 2017). In the context of ever more expensive workspaces, making the most out of office space is likely to be a clear organisational priority, globally and in the UK. **High rental costs are key drivers of using office space efficiently**

(Marmot, 2016).

In contrast to developing countries, the rate of new office space growth is relatively modest in cities that have large pre-existing office building stocks, such as London or New York (Marmot, 2016). Increasing densification of office space – in New York (Cushman & Wakefield, 2017b) or in UK cities, as shown by the British Council for Offices (BCO) Occupier Density Studies (BCO (British Council for Offices), 2009; BCO, 2013) – may mean that *less* space needs to account for a diverse array of activities. **In this context, the *quality of the physical workspace* is perhaps increasingly important.**

2.1.4. The office workspace: From cost to value

The following section presents several perspectives on the importance of workspace productivity and wellbeing emerging from professional body and corporate reports.

The *Commercial Offices Handbook* developed by Royal Institute of British Architects (RIBA) (Battle, 2003) highlights a disconnect - or "conflict of interests" (Duffy, 2003: 1) between the supply and the demand side of the process connecting office workers with office workspaces. To property developers and the financial institutions that support them – i.e. the supply side – "property is merely a commodity" (: 1), while for occupiers, office workspaces are key business tools by which they may gain competitive advantage.

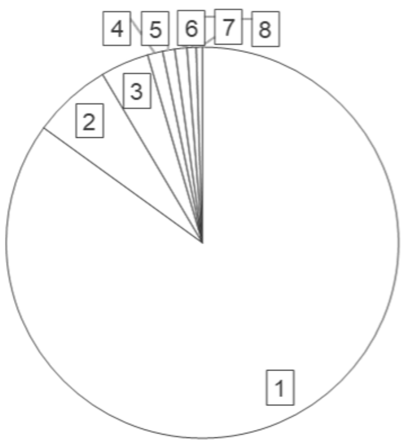
From the **property developer perspective**, decisions about where and how to build an office building develop within the realm of risk and reward. As some or all of the capital needed to finance a development is borrowed and bank loans may be difficult to obtain:

> "The developer will decide what profit margin he requires first, and then work with the rest of the variables to see if he can

> mould together a set of numbers that makes sense of the land price and the construction cost, when compared with the likely value of the completed product" (Barwick and Elliott, 2003: 34).

For the occupier, the office building is one of the factors of production, therefore being able to operate it efficiently over the entire length of the lease is the key interest. The average costs of developing and operating an office building in the UK for 25 years, the typical duration of a lease, are summarised in figure 2-2., together with the cost of salaries of the workers accommodated within. Salaries equate to 85% of the building's total cost, while costs related to the building and its operation appear relatively minor.

Figure 2-2. 25-year expenditure profile of office occupiers including salary costs. (Morell, 2003: 47)



1	Salaries of occupants	85%
2	Building - construction cost	6.5%
3	Mechanical and electrical (M&E) services - running and maintenance	4%
4	Furnishings and furniture	1.25%
5	Building - maintenance	1%
6	Cleaning, security etc.	1%
7	M&E services - depreciation	0.75%
8	Furnishings and furniture – maintenance and depreciation	0.5%

Therefore, quantity surveyor and British Council for Offices co-founder Paul Morell argues:

> "It follows that a very small movement in the productivity of their people, or in the quality of the work that they produce, would be far more significant than a major movement in the cost of the building" (2003: 47).

While the 85% figure[5] is a approximation and may vary according to the

[5] The 85% figure is also used by a recent report from the BCO exploring the '*Proportion of underlying business costs accounted for by real estate'* (Ramidus, 2016). The WGBC, (2014) estimates it at 90%.

exact specifications of different buildings and industries, staff costs are frequently cited as the **highest cost for occupiers in most service businesses**.

Growing interest in the effects that offices have on the wellbeing and health of occupants have informed the development of two comprehensive frameworks addressing workplace wellbeing. WELL® Building Standard (International WELL Building Institute, 2015) and the Fitwel® Rating System (Center for Active Design, 2018). While they approach wellbeing through different lenses, they address similar concerns, as shown below:

- WELL's occupant-centric perspective is clear from the way it conceptualises wellbeing using 'Concepts' associated with clear physical and psychological health intents. In the latest version of the standard (v2), the ten concepts are: *Air, Water, Nourishment, Light, Movement, Thermal Comfort, Sound, Materials, Mind and Community* (Delos Living, 2018). The first version of WELL (v1) included seven concepts: *Mind, Comfort, Fitness, Light, Nourishment, Water and Air*.
- The Fitwel approach includes twelve 'Strategies': Location, Building access, Outdoor spaces, Entrances and ground floor, Stairwells, Indoor Environments, Workspaces, Shared Spaces, Water Supply, Food Services, Vending machines and snack bars, and Emergency procedures. There are many similarities to WELL, however Fitwel has a stronger focus on the spatial qualities of the workspace environment, and related building safety and accessibility aspects.

In the UK, the British Council for Offices (BCO) has developed several initiatives highlighting the need to '*put people first'*, i.e. designing *for* the health and wellbeing of occupants (Clements-Croome et al., 2015). A recent initiative, entitled *Wellness Matters: Health and wellbeing in offices and what to do about it* (BCO, 2018) includes a comprehensive review of medical and behavioural research as well as a major survey of industry stakeholders. This initiative is based on a core belief that:

> "Businesses that invest in health [and] wellbeing will reap the rewards of increased productivity, lower costs from illness and enhanced reputation." (BCO, 2018: 9)

The report proposes a *Wellness Matters Roadmap* intended as a guidance tool. The Roadmap includes ten themes summarising 55 wellbeing outcomes: *Breathe, Clean, Touch, Hear, See, Nourish, Outside, Inside, Sense* and *Feel*. Most of these themes address physiological determinants of wellbeing defined as physical health, while the latter two touch on psychosocial dimensions.

Approaches such as the above highlight the importance of wellbeing for productivity from a financial perspective, such as a reduction of absenteeism (days of work lost because of health or wellbeing problems) – or presenteeism – (working when ill) (BCO, 2018; Clements-Croome et al., 2015; World Green Building Council (WGBC), 2014). Understanding wellbeing has clear benefits for the workforce. Research from Deloitte (2017) estimates that poor mental health costs UK public and private employers between £33bn – £42bn annually, with costs resulting from absence, presenteeism and turnover (figure 2-3 below).

Figure 2-3. Cost of mental health to UK employers. Adapted from Deloitte (2017: 6)

Absence cost: £7.9bn	+	Presenteeism cost: £16.8bn - £26.4bn	+	Turnover cost: £7.9bn	Self-employed absence cost: £0.9bn

Furthermore, the added benefit of an 'enhanced reputation' suggested by the BCO may refer to the *value* brought by workplace wellbeing initiatives, consistent with a broader 'wellbeing agenda'.

These initiatives demonstrate a growing interest in the effects of the workspace on occupant wellbeing, based on the need to enhance productivity. However, it is not yet understood how the physical and psychosocial aspects within the workspace environment may contribute to wellbeing or productivity.

2.1.5. Knowledge workers and knowledge work productivity

A recurring theme of workspace productivity and wellbeing research – academic and otherwise – is the increasing number of ‘knowledge workers’ in the workforce (Drucker, 1999; Ramírez and Nembhard, 2004; Robertson *et al.*, 2008; Bosch-Sijtsema, Ruohomäki and Vartiainen, 2009; Greene and Myerson, 2011; Cole, Bild and Oliver, 2012; Hills and Levy, 2014). This increased interest parallels the continuous development of the global services sector (‘the knowledge economy’), and gradual decline of industries dependent on manual work, as shown earlier.

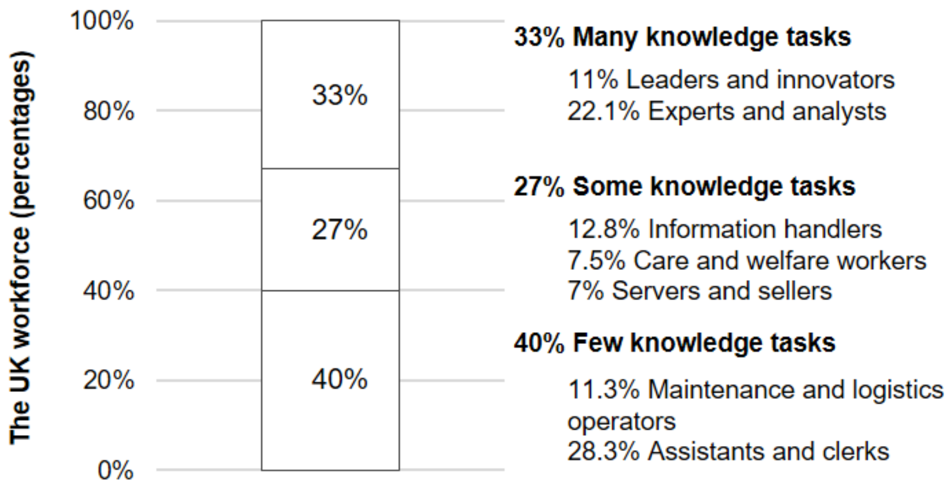
The term ‘knowledge worker’ was arguably popularised by management guru Peter Drucker in 1959 who used it to describe employees who work with intangible resources (Ramírez and Nembhard, 2004). Depending on the definition used, estimates of total number of ‘knowledge’ workers per country, sector, or globally, can vary. Researchers interested in UK workspaces like Oseland *et al.*, (2011) found that approximately 70 per cent of UK employees were knowledge workers in 2011.

Others, such as Brinkley *et al.* (2009), adopt a more granular distinction based on the frequency of performing knowledge intensive tasks, as shown in figure 2-4 below. Based on a survey completed by a sample of 2,011 with demographic characteristics “comparable to those found in the 2007 Labour Force Survey…data” (: 20), they found that 60 percent of the UK workers have jobs that require high or moderate knowledge content (figure 2-4). If we apply these ratios to the latest labour market figures provided by the ONS (2019b), i.e. 32.6 million people in work as of March 2019, the UK workforce includes approximately:

- 11 million whose activity involves many knowledge tasks;
- 8.6 million use some knowledge tasks;
- 13 million use few knowledge tasks.

The figure also shows that the **services sector is not completely comprised of office-based knowledge workers.** Occupations such as servers and sellers, care and welfare workers may be situated towards the middle area of the knowledge intensity spectrum, while maintenance and logistics operators, assistants and clerks, towards the lower area.

Figure 2-4. The 30-30-40 knowledge economy workforce. Based on data from Brinkley et al. (2009).



As suggested in chapter 1, the technological advances brought forward by the ‘Fourth Industrial Revolution’ bring “a mix of hope and ambiguity” for businesses worldwide (Deloitte, 2018: 2). Automation, machine learning, or high-performing computing create the opportunity to improve business processes (Cotteleer and Sniderman, 2017) but ‘Industry 4.0’ may also have disruptive effects on society and the workforce. Particularly, artificial intelligence (AI) is seen as becoming capable to replace a vast number of jobs that involve routine, low-skill tasks. In the UK, this would correspond to the 40% in figure 2-4 above, approximately 13 million women and men whose current skills may not only make them unemployed, but *unemployable*. To address this, they will have to reskill and upskill several times during their working life (ILO, 2019b). **Lifelong learning** seems to be the key element of securing work in the future.

Whatever the future challenges of knowledge work, there is broad agreement that the proportion of knowledge workers in the total workforce is increasing. **The problem of measuring knowledge work productivity is important but also a challenge precisely because knowledge work does not typically produce quantifiable outputs, but is quality-orientated**:

> "In most knowledge work, quality…is the essence of the output" (Drucker, 1999: 84)

In contrast to manual labour or industrial production, knowledge work imposes the responsibility of productivity on the workers themselves.

2.1.6. The rise of flexible working and choice of work space and time

In recent decades, advances in information and communication technologies (ICT) allow work to happen anytime, anywhere. Terms such as mobile working, telecommuting, teleworking, or e-working are often used interchangeably to describe remote working with the use of telecommunication devices (Morgan, 2004). Flexible working - a broad term used to describe flexibility over time or space of work, or a combination of both (Eurofound, 2017) – is increasingly being adopted across the globe, although at a different pace. Teleworking adoption is summarised below (table 2-2).

Table 2-2. Teleworking across the globe. Based on national studies compiled by Eurofound (2017)

Country / Geographical area	Percentage of teleworking from total employment	Year
European Union (28 member states)	17	2015
Sweden	32	2012
Finland	28	2013
Belgium	20	2011
Netherlands	15	2014
France	12	2012
Germany	12	2014
Spain	7	2011
Italy	5	2013
Hungary	1	2014

US	20	2012
India	19	2015
Japan	16	2014
Argentina	2	2011

In the UK, flexible working has increased significantly in the last decades (Morgan, 2004). Home-working alone has increased from 2.9 million workers in 1998 (11.1% of total employment) to 4.2 million in 2014 (13.9%), based on data from the ONS (Office for National Statistics, 2014). Since June 2014, when provisions were set out in the Employment Act of 1996, all UK employees have obtained the ‘statutory right’ to request flexible working after 26 weeks of employment, as shown by the Advisory, Conciliation and Arbitration Service (Acas, 2014). According to research from the Chartered Institute of Personnel and Development (CIPD, 2016), part-time working is the most common type of flexible work arrangement offered by UK employers (62%), followed by ‘flexi-time’ (i.e. flexible working hours, 34%), and regular working from home (24%). Other options include compressed working hours, career breaks, mobile working and job-shares (approximately 20% each).

A growing number of **academic studies** explore the benefits - and hindrances - of flexible working for productivity, wellbeing and other related outcomes. Gajendran and Harrison (2007) explored the benefits and disadvantages of telecommuting[6] by conducting a meta-analysis of 46 studies involving nearly 13,000 employees, finding positive effects on performance, job satisfaction, turnover intent, and job-related stress. Redman, Snape and Ashurst (2009) surveyed 749 UK managers and professionals employed by a management consultancy firm (: 174) in an exploration of home-based and office-

[6] Telecommuting is defined as “an alternative work arrangement in which employees perform tasks elsewhere that are normally done in a primary or central workplace, for at least some portion of their work schedule, using electronic media to interact with others inside and outside the organization. (Gajendran and Harrison, 2007: 1525)

based working effects on wellbeing and other outcomes. They found that, after controlling for total hours worked, home-working was positively associated with wellbeing. Grant, Wallace and Spurgeon (2013) conducted in-depth interviews with eleven UK e-workers[7], exploring aspects of productivity and wellbeing. The possibility to work remotely enhanced participants' productivity and wellbeing, improved their work-life balance, and reduced their stress and absenteeism. Wohlers and Hertel (2018) conducted a three-wave longitudinal interview study on 25 employees who relocated from single or shared offices to an activity-based flexible office[8]; researchers explored effects on work processes. Positive effects of working in the activity-based office were found on collaboration across teams due to increased contact, and better communication; however, teamwork was negatively affected.

The benefits and disadvantages of flexible working from the employee perspective have been explored by the CIPD on a sample of 1,051 UK workers (2016). The report showed that employees who used flexible working were more likely to report being satisfied with their job and work-life balance and were less likely to report being under pressure at work, compared to employees who did not work flexibly.

Data from academic researchers and statistical institutes suggest a relationship between work type and work mode: **employees who work flexibly tend to be knowledge workers, i.e. have highly skilled occupations.** Based on data from the 2001 UK Labour Force Survey, Morgan (2004) found that most of UK telecommuters were managers and senior officials, professionals, associate professionals or had technical occupations. Ten years later, data from

[7] All participants "worked remotely using technology independent of time and location for several years" (Grant et al., 2013: 529)

[8] Activity-based flexible office is defined as "a main open-layout environment without assigned workstations and provided additional working zones appropriate for specific work activities" (Wohlers and Hertel, 2018: 1)

the UK Office for National Statistics, ONS, suggest a similar pattern regarding employees who work from home regularly. Almost three quarters (73.4%) of the 4.2 million UK homeworkers worked as managers, directors and senior officials; professionals; associate professionals and technical occupations; or skilled trades (Office for National Statistics, 2014). Ojala and Pyöriä (2017) have assessed the prevalence of mobile, 'multi-locational' work across Europe (the 28 states of European Union, Norway and Switzerland) among workers with knowledge-intensive, versus 'traditional' occupations. Based on nationally weighted data from the Sixth European Working Conditions Survey conducted by Eurofound in 2015, their analysis found that mobile working "is most common in northern European countries, where the proportion of knowledge-intensive occupations is high" (: 402).

2.2. Foundations of workspace observational research

Literature discussing office workplace productivity (Bedeian and Wren, 2001; Olson *et al.*, 2004; Clements-Croome, 2006; Knight and Haslam, 2010; Kiechel, 2012) often cites two influential works. These are Frederick Winslow Taylor's *Principles of Scientific Management* (Taylor, 1911), and Professor Elton Mayo's *Hawthorne Studies* (Roethlisberger and Dickson, 1939/1961). Although different, both are essential steps in the evolution of systematic observation in workplace management theory (Bernstein, 2017). Their key implications for workspace productivity research are presented in the following sections.

2.2.1. Scientific Management

The ideas and methods of Scientific Management ('SM'), as proposed by Frederick Winslow Taylor (Taylor, 1911) have had considerable influence on workspace management and organisational theory, as well as office layout design (Clements-Croome, 2006; Drucker, 1999; Duffy, 2000; Gartman, 2000;

Guillen, 2006). *The Principles of Scientific Management* is possibly the most cited management book of the 20th century (Bedeian and Wren, 2001; Wren, 2011). Scientific management has not only been associated with the beginnings of workplace productivity measurement, but also with the foundations of office building design (Haynes, 2007) and even the rise of modernist architecture (Guillén, 2006).

Taylor's fundamental aim was to improve the efficiency of the manual work process, by proposing a new type of management, based on clear laws and principles – i.e. 'the science' of work. (Taylor, 1911), which was to replace rule-of-thumb methods largely used at the time. The principles of Scientific Management (SM) place a particular emphasis on the new role and duties of the manager: "In the past the man has been first; in the future the system must be first" (1911, Introduction, par. 9). Firstly, in SM, managers have the responsibility of developing a science of the work, which is to replace the rule-of-thumb methods largely used in the trade. This is to be done by dividing the work – any type of work – into units (or steps) whose execution can be precisely timed using a stop-watch. Secondly, in SM, managers are responsible for the 'scientific' selection of the workers most suited to perform the work, followed by their training and development.

In SM, **the worker is reduced to the status of mere executant of a work entirely planned by others hierarchically above him,** however at the time, Taylor's principles were presented as a way of empowering workers and helping them reach maximum 'prosperity'. However, fear was an important element of this system, as the workers who fail to perform are first warned, then fired. Moreover, the 'training, teaching and development' of the worker is in fact aimed at improving his abilities to do *the same* work better, rather than teaching or encouraging him to develop new skills that might, in time, help him reach outside his ‘class of work’.

It should be noted that the core elements of Taylorism are standardisation and planning of *work*, not of the *workspace*. The only direct reflection that Taylor makes on the actual workplace environment is the observation that planning of work under SM requires the building of a labour office for the superintendent and clerks responsible for managing the work. However, the application of SM led to an important increase in workplace bureaucracy and office hierarchy especially in America (Saval, 2014).

Taylor’s perspective on workers as “units of production rather than as thinking, feeling, sentient human beings with intelligence and wills of their own” (Duffy, 2000: 371), became influential for office layout design, with a particular emphasis placed on managers’ **control and ability to oversee work**.

2.2.2. Human Relations - The Hawthorne Experiments

In parallel a new vision of the worker and the importance of good employee relations emerged in the 1920s and 30s. Between 1924 and 1933, a series of experiments were conducted at the ‘Hawthorne Works’ plant of the Western Electric Company - the manufacturing arm of American Telephone & Telegraph, (AT&T) - located in Cicero, outside Chicago, Illinois (Harvard Business School, 2012 a). A team of researchers from the Harvard Business School[9] became Western Electric’s academic collaborators in a series of research studies aimed at observing the effects of changes to the work environment on productivity. The Hawthorne Studies – fully presented in Roethlisberger and Dickson’s *Management and the worker* (1961, first published in 1939) – became “a landmark study of worker behavior” (President and Fellows of Harvard College, n.d.) and may have been influential in the formation

[9] then the Harvard University Graduate School of Business Administration

of the Human Relations Movement (Olson et al., 2004).

Previous experiments had been conducted in 1924 to study the effects of lighting on worker productivity, revealing that “light is only one, and apparently a minor, factor among many which affect employee output” (Roethlisberger and Dickson, 1939/1961: 5). Following the *Illumination experiments*, a new study was conducted to investigate the relations between specific measurable workplace conditions (temperature, humidity, hours of sleep) and workers’ fatigue and productivity. The initial scope of the *Relay Assembly Test Room* study was extended several times, as shown below.

The large number of variables thought to influence worker productivity (suggested by the Illumination tests) led to the development of the Testing Room Method. A small group of employees were selected based on their previous experience as relay assemblers. The “general health and wellbeing” of the employees was explored regularly, and the operators underwent periodical physical examinations every six weeks (: 28). The workers were also surveyed at the beginning of the study. The job chosen for the experiments was the assembly of telephone relays – an operation performed by female employees consisting of assembling together 35 small parts into a fixture. The repetitive task took about a minute to complete. Performance was objectively measured using a device that perforated holes in a paper tape, as relays were completed (figure 2-5).

Figure 2-5.Hawthorne Relay Assembly Test Room. (Roethlisberger and Dickson, 1939/1961: 25)

To create fully controlled conditions for the researchers, participants were isolated them from the regular fluctuations of the workplace. The experimental room was a well-lit 52 square meter (562 square feet) space that was similar to other relay assembly rooms. A daily history record (DHR) recorded hourly temperature and humidity data for several years.

The tests were organised in ‘periods’ which investigated the effects of a different test condition on the operators’ output. The first two periods were preparatory and used by the researchers to measure the baseline values of the study, e.g. average hourly output, time required to assemble one relay etc. The following eleven periods (April 1927 to June 1929) tested additional conditions, including the introduction of a piece rate payment system, and different rest periods in the work schedule. **Some of the different testing conditions were suggested by the subjects themselves**.

The weekly average hourly output of each of the five operators throughout the study periods showed that an upward trend was generally maintained throughout the various stages. **It appears that even working under 'unpopular' conditions the operators managed to work faster and better than ever before**. As the experiments have tested combined, rather than isolated variables, the experimenters were unsure which of the changes were causing the increase. A confounding effect was likely present.

2.2.3. Lessons learned from Scientific Management and the Hawthorne Studies

These two early examples of observation of workplace behaviour and productivity invite reflection on their methodological advantages and faults.

First, the scientific management theory – one of the most influential management theories to date – was less a method, and more a generalisation based on Taylor's own (perhaps biased) views. Taylor went from observation of the outcome to observation of the process (Bernstein, 2017), and then, to wide generalisations. While relying on precise tools for measuring the output of work (such as the stop-watch), he ignored all other aspects that may support or disrupt the ability to work. His theory is based on anecdotal evidence gathered on small samples and in circumstances favourable to Taylor's hypothesis – e.g. his selection of 'proper' subjects for his experiment pig-iron handlers. Nevertheless, the success of simple "stories about the optimization of tasks as simple as pig-iron work, bricklaying, and shoveling" (Bernstein, 2017: 14), and the use of straightforward tools made his theory appealing for decades to come. As suggested by architect Francis Duffy, the office skyscraper may symbolise the "values of machine-like organisations: order and discipline, supervision and hierarchy, command and control" (Duffy, 2000: 371).

In contrast, the Hawthorne Studies showed determination to understand

worker psychology by exploring new territory. For the most part, the studies employed a thorough methodology including participant selection; setup of the experimental settings; selection of clear and measurable outcome method; long duration of the observation period. The sample was small, but the conditions of the study were – initially – fully controlled by the researchers. However, the studies failed to demonstrate an actual causation between the various test conditions and the output. The output continued to increase throughout the various experimental conditions. Perhaps **the growing attention given to the operators** positively impacted on their productivity. Participants were generally encouraged to talk more freely in the test room than they would do in the regular department, they undertook physical examinations, they had been invited to the office of the superintendent etc. Also, the test room environment was being perceived by the workers as being better than the regular department settings – it was a better lit, better ventilated space. Also, as researchers pointed out "sociologically speaking, the girls were members of a small group rather than of a large one" (p. 39). The test room was perceived as "fun" and the operators hoped the experiments would continue for a long time (p.71). Importantly, the operators were permanently consulted, which resulted in the continuous modification of the experimental conditions *according to their suggestions*. The Hawthorne researchers may have underestimated their own influence on the subjects, in particular the workers' **desire to perform well when placed under observation**. This has been called the 'Hawthorne effect', a phenomenon which should be considered when designing any experiment (Hammond, 2009).
Several implications for observational workspace research can be derived from the Hawthorne experiments:

- the need to develop the hypothesis and study design *prior to (and independently from) the data collection* process*;*

- acknowledge – and control for – participants' altered behaviour when being placed under observation.

The Hawthorne studies were extremely influential. They (accidentally) revealed a great variety of phenomena that are relevant to the human wellbeing, as a pre-requisite of productivity. The term 'organisational behaviour' was apparently coined by Fritz Roethlisberger himself "to suggest the widening scope of 'human relations' [the term used at the time]" (Buchanan and Bryman, 2007: 484). In the following decades, organisational research became sensitive to changes in society, individual particularities and preferences, and so now includes topics that were completely ignored before the Hawthorne studies.

2.3.The 'Workspace': Physical determinants of productivity and wellbeing - Systematic review of literature

2.3.1. Background and Objectives

The relationships between the workspace, productivity and wellbeing are not well understood. A systematic review was conducted to identify, critically assess and synthesise empirical evidence based on previous research published in peer reviewed journal articles published in the previous decade. The advantages of using systematic reviews to answer a specific research question are related to their use of explicit and systematic search methods that are based on pre-specified eligibility criteria and thus minimise bias; systematic reviews lead to more reliable findings from which meaningful conclusions can be drawn and decisions made (Higgins and Green, 2008; Liberati et al., 2009; Moher et al., 2009).

The systematic review had the objective to collate, synthesise and review evidence-based workspace productivity and wellbeing research with a specific focus on understanding:

- Which key concepts are associated with office workplace health, wellbeing and productivity (the ‘predictor’ variables);
- How are productivity or performance measured;
- What study designs are employed by researchers and what are their strengths and weaknesses.

2.3.2. Data sources and search methods

The SCOPUS database (Elsevier, 2019) was used for identifying the articles relevant to the research. The search used the terms “office” OR “workplace” AND “productivity” OR “wellbeing” OR “performance” (In: *Article Title / Abstract / Keywords*). The following limitations were applied and maintained throughout the subsequent searches: Published 2005-2014; Document type: Article; Language: English; Source: Journals; Subject Areas: Life Sciences + Health Sciences + Physical Sciences + Social Sciences & Humanities.

The search retrieved 9,772 results from a total of 28 Subject Categories. The next search filtered the results by excluding a variety of Subject Areas considered out of scope. Next, a search for the phrase “office productivity OR performance AND evaluation” was performed within the 3,209 results. By limiting the search terms to specific Subjects, two distinct groups of articles were created:

- (Limit to) Business, Management and Accounting + Decision Sciences + Psychology + Social Sciences – 189 results;
- (Limit to) Engineering + Environmental Science + Multidisciplinary + Neuroscience + Undefined – 353 results.

The two sets of articles were further analysed by reading the article Abstracts. This revealed a great variety of research themes that, while addressing aspects related to workplace productivity and wellbeing, focussed on psychosocial factors, such as employee personality, workplace empowerment, organisational citizenship behaviour, and motivation. It was decided to exclude all articles that did not specifically address any *physical attributes* of the workspace from the review. This led to a severe limitation of results: just three of the 189 Social Sciences articles met this criterion.

The Environmental Sciences results revealed specific physical concepts that are associated with productivity, such as temperature, air quality or light. The next step was to conduct specific keyword searches for (“office productivity” AND [keyword]), read the abstracts and select the evidence-based articles that met the criteria.

2.3.3. Results and Discussion: Key concepts and metrics

The refined search retrieved 34 articles discussing several key concepts related to workspace productivity and/or wellbeing: three articles with **social sciences** scope and 31 adopting an **environmental sciences** approach.

(A) SOCIAL SCIENCES

Haynes (2008) developed a theoretical framework for evaluating office productivity, tested using questionnaire studies on two samples. The first dataset includes answers from 996 respondents from 10 public sector local authorities (26 offices), and the second includes 422 respondents from one large private company (four offices). Overall, most respondents (83%) worked in open plan offices, and 16% in cellular offices. Four types of work were analysed:

- individual;
- concentrated study work (less than 60% of time spent with colleagues, high degree of flexibility of where and how work is performed);
- group work (over 60% of the time spent with colleagues),
- transactional knowledge (over 60% time with colleagues and high work flexibility).

Haynes' model reduced 27 evaluative variables to four components: *comfort* and *office layout,* and *interaction* and *distraction*, respectively. Of the four components, the study found distraction – comprised of noise, crowding and interruption - to have the most significant effect on individual process work productivity: a negative one. For all types of work investigated, the behavioural components of the office environment were found to have a greater effect on productivity than the physical components. However, as this study is based on subjective evaluations only, it is indicative of people's *perception* of the four components. It may be true that while distraction and interaction are easy to perceive, the complex mechanisms of the physical environment (some of which are not easily noted solely through direct observation) may go unnoticed.

Kwallek et al. (2005) compared the effects of three interior colour schemes on the job satisfaction, perceived performance and stimulus screening ability of 90 participants in a four days laboratory experiment. The study was conducted in three simulated office spaces (2.63 m wide, 3.25 m long, and 2.44 m high) in which the walls, desk, door, and all desk accessories were finished using three different colour schemes: white, red and blue-green, respectively (n=30 each). Pre-testing screening included a timed typing test, and psychological and physical conditions (personality and achievement striving, and colour blindness and stimulus screening ability, respectively). Subjects were assigned to specific experimental conditions according to their sex and stimulus screening ability, excluding all other group differences. Participants performed a variety of office tasks in four consecutive sessions of eight hours each, with a lunch break and two 15 minutes breaks each day; two tasks of fifteen minutes each were performed at the beginning of the day and after each break. Details of the 'office tasks' and task performance results are not included in the report. On the fifth day, participants completed a seventeen-item questionnaire on *perceived* *performance* and *job satisfaction*. Results showed that the questionnaire ratings were significantly higher for subjects who worked in the white office, compared to the red office, however the ratings were similar to those of the individuals in the blue-green office; these results were not dependent on the subjects' screening ability. However, the subjects' *perceived* performance may not necessarily indicate their actual performance or productivity. Furthermore, as acknowledged by the researchers, the high performance and satisfaction ratings given by subjects working in the white office may also be a result of habit and expectation, as "White or off-white is the ubiquitous color palette for most commercial spaces in our culture" (Kwallek et al. 2005: 484). Thus, *social expectations* of specific office colour schemes could have a role in mediating the relationship with worker performance.

The relation between an organisation's managerial style and its physical workplace may translate into different types of offices with different effects on employee productivity. Knight and Haslam (2010) conducted two experiments that tested four office conditions:

- the lean office – a minimalist office which only includes elements directly related to the work process;
- the enriched condition - plants and art are present, but not chosen by workers;
- the empowered office – workers design their own workspace, choosing from a selection of plants and art;
- the disempowered office space – the personalised design created in the third condition is changed (overridden) by the researchers, who displace the plants and art *in front of the participants*.

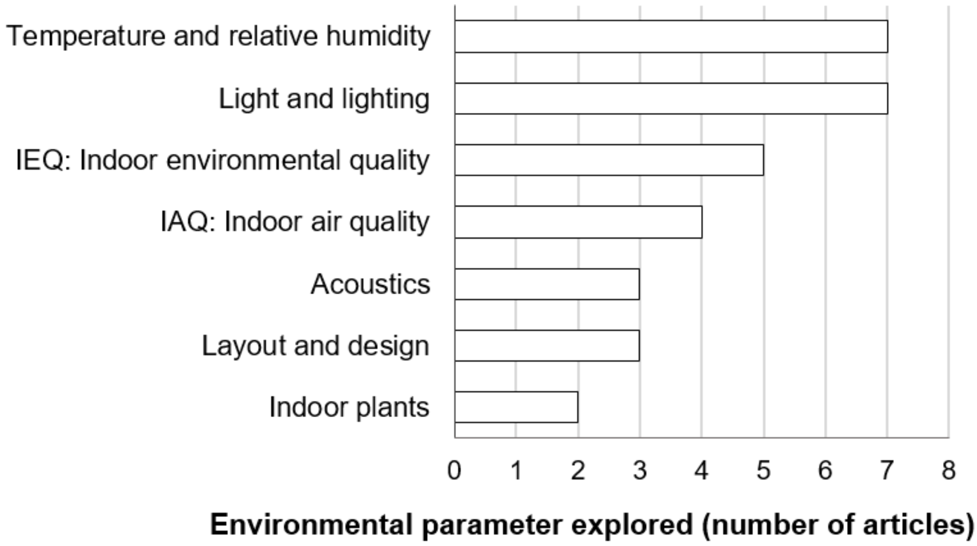
They measured performance on timed tasks, and wellbeing (conceptualised as psychological comfort, job satisfaction, and physical comfort, organisational citizen behaviour).

The first experiment was conducted in a university psychology department on a population of 112 participants (mean age: 38), 31% students, 61% paid employees and 8% retired. A windowless, simulated office space of 3.5 m x 2 m with constant room temperature of 21°C and a desk and chair was used for the experiment. Under all four conditions, participants were asked to perform two tasks in which speed and accuracy ('productivity') were measured: a card-sorting task and a vigilance task; duration of the experiment is not specified. After the completion of tasks, subjects filled in a questionnaire with 74 questions, asking their perception of the managerial control of space, psychological comfort and organizational identification, and the positive experience of work – comprised of job satisfaction and physical comfort. The second experiment was conducted in a 4.5 x 6 meters space belonging to a commercial office space in London. The sample (n=47; mean age=36) was comprised exclusively of office workers. Furthermore, the tasks completed by the participants were more similar to real office jobs: information management and processing task; vigilance task; organizational citizenship behaviour (OCB) task (based on the fictitious employment of participants with the company described in the first task). Results of the first experiment showed that participants in the lean condition "felt less psychologically comfortable, reported less job satisfaction, and expressed lower feelings of physical comfort than participants in other conditions", and took the longest time to complete the tasks (Knight & Haslam 2010: 162). Disempowered condition participants reported lower psychological and physical comfort, compared to the participants of empowered and enriched conditions. Results of the second experiment generally confirmed the findings of the first one, and further showed that participants in the empowered condition showed higher OCB.

(B) ENVIRONMENTAL SCIENCES

The 31 articles that adopted an environmental sciences approach associated productivity and/or wellbeing with seven parameters, as summarised in figure 2-6 below.

Figure 2-6.Parameters explored by articles with environmental focus (N=29)



TEMPERATURE

Seven articles in the review explored the effects of temperature on productivity or performance.

Valančius & Jurelionis (2013) conducted a simulated office environment laboratory experiment to test the effects of indoor temperature variation on work performance (text typing, solving arithmetic tasks and the Tsai-Partington test, respectively) and thermal sensation (measured using the seven-point predicted mean vote scale, or PMV) on a sample of 78 individuals in Lithuania. One group experienced a constant air temperature of 22°C throughout the 1 hour and 45 minutes experiment, while the other two experienced a 4°C temperature change from 22°C to 18°, and 26°C, respectively. Compared to the initial case, the drop of temperature to 18°C increased overall productivity by 5.2% (with a 13.9% higher accuracy on the Tsai-Partington test), while the temperature rise from 22°C to 26°C decreased productivity by 0.1%, not a large effect.

Kekäläinen et al. (2010) analysed the implications of summer temperatures on worker performance in an intervention study of two floors of an office building from Helsinki during two successive summers – before and after the renovation of its air conditioning systems. The sample included 118 (before) and 133 participants after renovation (overlap not specified). The study used the subjective assessment of employee productivity and of the indoor air quality (measured with questionnaires); for a smaller population performance was also objectively measured by timing the duration of two calculation and data processing tasks. Overall the study found significant decrease of the percentage of people dissatisfied with the air temperature and quality and workers who reported working under their average efficiency after renovation. Objective task performance measurements found an 8%, and 2.2% increase.

High indoor temperature has been found to be connected to performance as well as fatigue, by a series of experiments monitoring the cerebral blood flow of 40 participants (20 M, 20 F), who were asked to perform office-type tasks, report on their thermal sensation and fatigue and evaluate the task load (Tanabe et al., 2007). Hot environments (33.0°C and 33.5°C, respectively) were shown to require more cerebral blood flow to maintain the same level of performance. Furthermore, a climate chamber experiment tested the effects of combining different air temperatures with different clothing insulating values (clo) of the subjects - 25°C with 1.0 clo, 28.0°C with 1.0 clo and 28.0°C with 0.7 clo - on the participants' ability to solve nine calculation tasks. Performance was significantly lower after the 6th session at 28.0°C with 1.0 clo and was also lower at 28.0°C with 0.7 clo. Thus, while subjects were able to maintain their performance in the short term (1.5 hours), high indoor air temperature was suggested to have a negative effect in the long term. In "hot and dissatisfying environments" fatigue and mental effort continued to increase, which was supported by the subjects' higher evaluation of fatigue at 33°C, compared to 25.5°C and 28.0°C (Tanabe et al. 2007: 632).

The impact of four indoor air temperatures (19°C, 24°C, 27°C, and 32°C) on the productivity of 24 participants was also measured using a neurobehavioural approach that tested the perception, learning and memory, thinking and executive functions, as well as the subjective measurements of the subjects' thermal sensation (Lan et al., 2009). Nine neurobehavioural tests were taken in 80 minutes sessions – *overlapping; conditional reasoning; spatial image; memory span; picture recognition; visual choice; letter search; number calculation; symbol–digit modalities test*. The relation between temperature and performance was influenced by the type of task, as different tasks require the predominant use of different parts of the brain hemisphere and cortex. The accuracy of left hemisphere dominant tasks such as *letter search, conditional reasoning,* and *number calculation* peaked at 24°C, while for right-hemisphere tasks like *overlapping, spatial image,* and *visual choice* the accuracy peaked at 27°C. However, warmth (even moderate) was shown to negatively affect performance overall. The study also showed that the participants' short-term performance could be maintained even under adverse conditions (hot or cold), if motivation was present: participants want to finish the task quickly and escape the uncomfortable environment as soon as possible. Another explanation could be related to the 'Hawthorne effect', i.e. participants' desire to perform well when placed under close observation. There was also a difference between the accuracy of most tests solved in the two different times of day. Tests solved in the afternoon sessions were more accurate than those solved during the morning session, which may be a result of *circadian effects* or of a learning effect.

Similar results were found by Lan and Lian (2009), who tested the impact of temperature on 21 subjects asked to perform thirteen neurobehavioural tasks – four tests were added to the nine tests previously used by Lan et al. (2009): *event sequence; reading comprehension; graphic abstracting* and *hand–eye coordination.* While the different temperature affected performance differently according to task type (as above), the average performance decreased at slightly uncomfortable conditions (warm and cool), and the subjects had to exert more effort in order to maintain performance under moderately adverse conditions.

Building on previous research, Lan et al. (2010) tested the effect of 17°C, 21°C and 28°C temperatures on productivity by measuring the subjects' heart rate variation (HRV) and monitoring electrophysiological activity using an electroencephalograph (EEG) as they performed the 13 neurobehavioural tests, as well as drawing insights from their subjective evaluations of emotions, wellbeing, motivation and task difficulty. Under high temperature, the participants' ratio of low to high frequency of the HRV increased (it was highest at 28°C), which explained the drop in wellbeing perception. Overall, the study found that under "moderately uncomfortable environment" (either high or low temperatures), the subjects "had to exert more effort to maintain their performance with the increase of workload" (Lan et al. 2010: 36), and their motivation decreased.

In a climate chamber experiment, Tsutsumi et al. (2007) tested the effects of temperature and relative humidity combinations on the productivity of 12 subjects who performed addition and text typing tasks. The experiment tested the following variables: 15 minute exposure to 30°C and 70% RH, the subjects wearing clothing with 2.0 clo (Chamber 1); 180 minutes exposure to a constant temperature of 25.2°C and 0.67 clo value and successive RH percentages of 30%, 40%, 50% and 70% (Chamber 2). Physiological measurements were also taken, such as skin wittedness and moisture, and the subjects rated their thermal sensation, comfort sensation and humidity sensation, as well as their perceived fatigue and pleasantness of the environment; they also measured their break up time. Physiological measures showed that skin moisture and humidity decreased rapidly at lower RH conditions, indicating that more body sweat (evaporation) occurs in lower humidity conditions. Thermal sensation did not change, as the temperature was maintained constant throughout the experiment conducted in Chamber 2. Performance did not change throughout the experiments, possibly because of the limited exposure period, however it is suggested that longer term exposure to high humidity might affect productivity, as subjects reported to be more tired at 70% RH.

A general observation can be made based on the articles included in this section. Most of the studies only address the effects of air temperature on thermal comfort, without acknowledging the human behaviour component – i.e. people's ability to regulate their level of comfort for example by adjusting their clothing or changing position. This narrow perspective limits the applicability of results for real life settings.

LIGHT AND LIGHTING

Seven articles included in the review addressed aspects related to natural light and/or artificial lighting.

Kim & Kim (2007 a, b) studied the effects of fluctuating illuminance on visual perception and performance in a 40 minutes experiment conducted with 36 participants in a simulated office environment. The 3 m x 3.6 m x 2.4 m (width / depth / height) experimental room was windowless, had wall and ceiling surfaces finished in white, and was furnished using a typical office desk and chair. Desktop illuminance fluctuation was tested by alternating between base level and six different ranges of illuminance. Subjects completed a letter identification task based on texts printed on standard letter-sized paper. After each change in illuminance level, participants evaluated the level of their annoyance in relation to the lighting conditions, and visual responses at constant illuminance levels. While differences were found among the subjects' reported visual comfort at different illuminance conditions (e.g. constant 500 lx level was considered too dim for the solving of the paper task, compared to 650 lx), the letter identification task scores were not found to be influenced by the fluctuating light, perhaps due to the short time of exposure. Regarding office space lighting, the researchers recommend a minimum task illuminance level of 650 lx and a fluctuation of illuminance lower than 40% (Kim & Kim 2007b).

The effects of colour temperature lighting on employee performance and wellbeing was also studied by Mills et al. (2007). A 14-week controlled intervention study was conducted on a population of 69 employees working on two floors operated by a UK call centre; the organisation operated in 12 hour long shifts (8am-8 pm). For both floors, baseline light levels were at 2900 K colour temperature, which remained unchanged for the control floor throughout the study. For the 'intervention floor', all lighting fixtures were replaced with 17000 K colour temperature fluorescent lights after baseline measurements, without informing participants of the change. Effects were evaluated using questionnaires completed at baseline and after the three months intervention period. Respondents evaluated aspects related to their alertness, ability to concentrate, job performance and general wellbeing. The Short-Form 36 quality of life scale (Hays et al., 1993) was used to assess wellbeing (five relevant items selected for the analysis). Results suggested a positive effect of the lighting change. The intervention floor sample had an over 30% improvement of the self-assessed concentration, light headedness, lethargy and sleepiness, and a 20% increase in self-reported work productivity. However, the difference between the control floor and intervention floor samples (n=23 and n=46, respectively) acts as a limitation of the study's validity.

Wei et al. (2014) analysed the combined effects of two office lighting variables – correlated colour temperature ('CCT', 3500 and 5000 K) and lumen ('lm') output of fluorescent lighting (2300 and 3000 lm) - over a three month long field study. Research was conducted in multiple areas of a four storey office building in the USA, including open-plan, cubicle, and private offices and shared spaces. Data on perception and satisfaction with the environmental conditions (particularly the visual environment), perception of health and wellbeing, and also self-perceived productivity were gathered from the 26 participants using brief and frequent ecological momentary assessments (EMAs) and longer, more complex web-based surveys. Results showed that perceived productivity decreased at the higher CCT, and the most negative effect was found at the combination of 5000 K CCT and 3000 lm; this combination was also rated, on average, as too bright. Overall satisfaction and satisfaction with colour temperature also confirmed that 5000K conditions were evaluated as less comfortable (or 'too cool') than 3500K (just right), especially by respondents who had daylight access in their offices. The method chosen by the researchers allowed for the collection of detailed observations over a longer period of time than most other studies in this review.

Ko et al. (2014) studied the effects of font size and reflective glare on the performance of 19 'young' (18-35 years old) and eight 'older' (55-65) participants on common visual tasks: a visual search task and two matching tasks performed under 'average office lighting' conditions. The experiment tested two variables: *text size* - small (8 pt), medium (10 pt), and large (16 pt) Arial font; and the presence or absence of *glare* –as produced by a luminaire reflected off the matte LCD monitor. Results found no interactions between the participants' age and their productivity, accuracy or perceived task difficulty, or between font size and glare. However, font size was found to significantly affect all these variables, with the largest font being associated with an increased speed and accuracy on task solving, as well as the perception of the task as being easier than tasks performed with smaller font sizes. Increasing font size from small to large led to a 30% improvement in productivity and 3% in the accuracy of solving tasks. However, given the relatively small sample size (especially for the 'older' age group), these results may be challenged by further research.

The relationship between light and performance may be mediated by *non-visual* effects of light on human wellbeing, such as light's role in "the maintenance of the physiological circadian profiles" (Hoffmann et al. 2008: 720). The effects of various lighting conditions – intensity and colour temperature – on mood and performance was investigated by Hoffmann et al. (2008) in a simulated office experiment with 11 participants conducted in two distinct sessions. Two lighting intensity and colour temperature conditions were tested in two otherwise identical rooms (20 m^2, 2.4m height, 23°C ± 2°C temperature). Physiological parameters related to the circadian rhythms were measured three times during each experimental day: Sulphatoxymelatonin i.e. "the stable urinary metabolite of melatonin", and Neopterin, "a marker of an activated cellular immune system that shows a circadian pattern" (Hoffmann et al. 2008: 720). As both parameters have a 24-hour rhythm (highest concentration in the morning, decrease during the day), the duration of the study sessions was set to three consecutive days (timing from 8.45 to 17.00), and the researchers collected three urine samples per day from all subjects. Throughout the experiment, the subjects completed mood rating inventories and performed simulated office work in the morning and afternoon for approximately 2.5 hours (the details and results are presented in a different paper, Hoffmann *et al.*, 2010). Results of the study offer limited evidence on the two lighting conditions' effect on the markers of the circadian rhythm. The mood rating results indicate a relationship between variable light and high 'activity' and 'concentration' and 'deactivation', which considered to be indicative of performance. Therefore, the study suggests a "potential benefit of a variable lighting installation in indoor office accommodations with respect to subjective mood and activation" (Hoffmann et al. 2008: 727). Elsewhere, Hoffmann et al. (2010) present the effects of these lighting conditions on other circadian rhythm parameters - blood pressure and heart rate, as well as the subjects' performance on general and specific ability tests. Blood pressure and heart rate values did not change significantly during the two lighting conditions and no light-dependent effects were found on the cognitive performance of the subjects. Perhaps due to their short duration, neither of the studies succeeds in demonstrating an unequivocal relation between light and performance, however they contribute to the wider understanding of the complex non-visual effects that light may exert on human behaviour.

IEQ: INDOOR ENVIRONMENTAL QUALITY

Five articles explored IEQ, a summary measure of environmental quality including several variables, such as temperature, air quality, noise, light and lighting etc.

Feige et al. (2013) studied the impact of sustainable office buildings[10] on the self-assessed performance and comfort of employees using a combination of methods. Firstly, researchers developed online questionnaires comprised of 170 questions representative of constructs such as: environmental features rating (18 questions about office features such as light, temperature etc.), IEQ (definition not provided), occurrence of Sick Building Syndrome (SBS), organisational citizenship behaviour (OCB), work performance, and work engagement. Questionnaires were completed during two seasons (summer and winter). Secondly, the researchers conducted structured interviews with building owners

[10] Defined by the authors using the three-pillar model of sustainability, which builds on environmental, economic and social perspectives. The authors' declared focus is on the social aspects, e.g. comfort of occupants.

and/or office managers, which included 60 questions on aspects such as social sustainability, user behaviour and complaints. Thirdly, physical measurements of environmental parameters – temperature, humidity, CO2, volatile organic compounds (VOCs) and airborne particle concentration, light and noise and acoustics – were taken in summer, and winter, respectively (one week each, resolution not specified). Complete results were obtained from approximately 1,500 employees working in 18 buildings. The study found that specific 'sustainable' features of the environment (e.g. operable windows, absence of air conditioning) do not impact directly on the employees' productivity, but on their comfort and work engagement. As the physical parameters associated with comfort were only briefly measured, the relationship is not likely to be causal. Furthermore, the relation between sustainable office building environments and productivity may be related to the *physical, functional and psychological comfort* of their occupants, as "building users feel the need to have an influence on their work environment and do not wish to work in buildings which are fully automated" (: 29). This corroborates with perspectives from Leaman and Bordass (1999) who argue that "people's perception of control over their environment affects their comfort and satisfaction" (: 4).

Hedge & Gaygen (2010) have tested the effects of the IEQ of an air-conditioned U.S. sales office on the computer work performance of 19 employees in a one-month long field study. Throughout the duration of the study, the following IEQ variables were monitored: air temperature and RH, CO_2, TVOCs and respirable particle matter at 10 microns concentration (PM_{10}), and noise levels. Performance was measured using a web-based software system that counted correct keystrokes, correction keystrokes and total keystrokes and mouse-clicks on a minute-to-minute basis. Air temperature was the only variable found to have a significant effect on productivity. At the highest temperature

(28°C, compared to the average 24°C), the correct keystroke rate was 34 keystrokes/minute, more than twice as the one achieved at the coolest temperature of 21°C (15 keystrokes/minute), however the average mouse click rate had an opposite trend (lowest rate at highest temperatures). Interestingly, the study found a relation between computer performance and the day of the week, with Monday being the most productive in terms of correct keystrokes and mouse-click rate, and Friday, the least.

Menadue et al. (2013) have used a combination of environmental data monitoring, collection of energy and water consumption data and subjective assessment methods in a post-occupancy evaluation of a sample of eight office buildings in Adelaide, Australia over a 12-month period comparing four Green Star-certified buildings to four conventional ones. Half-hourly measurements of indoor office temperature, humidity, and light levels were taken. The occupant survey was comprised of four categories: *environmental* (including questions on temperature, humidity, air, light, and noise), *design, operational* (control & management of the environment) and *people* (which included demographics and perceived productivity, morale and job satisfaction etc.). The total number of respondents was over 600. In comparison to conventional buildings, Green Star buildings were generally better perceived by their occupants in terms of overall comfort, perceived health, and winter and overall summer conditions, however perceptions of productivity, satisfaction with lighting overall, noise overall were lower in the Green Star buildings. A possible explanation could be related to the fact that Green Star buildings are predominantly naturally ventilated.

Singh et al. (2010) have investigated the relation between the costs and benefits of significantly improving the IEQ of office buildings, exploring the case of two companies from Michigan, US, that moved from conventional offices to Leadership in Energy and Environmental Design (LEED)-certified buildings. Pre-move and post-move data on perception of wellbeing and productivity were obtained from the employees of the two companies (56, and 207, respectively) via a 20-minutes long web-based survey. The occupant wellbeing survey section evaluated respondents' *health background* and *health snapshot*, i.e. conceptualising wellbeing as physical health, while the productivity section tested their *satisfaction with various IEQ attributes* and the perceived *effect of IEQ on productivity*. Results found that after the move to LEED buildings, average absenteeism and average work-hours affected by asthma/allergies, or depression/stress had dropped, thus productivity improved for the employees with a medical history of those conditions. Overall perceived productivity had improved significantly, which "could result in an additional 38.98 work hours per year for each occupant of a green building" (Singh et al. 2010: 1666).

Mak & Lui's (2012) questionnaire-based investigation of the relation between perceived productivity and five environmental office factors - temperature, air quality, office layout, sound and lighting - revealed that sound, temperature and office layout were the main factors considered to impact on productivity by the 259 office worker respondents. The sounds rated as being most annoying were conversation, ringing phones and machines, followed by non-specified noise sources inside and outside the office. This supports the findings of other studies that highlight speech as the single most distracting office sound (Kaarlela-Tuomaala et al. 2009; Haka et al. 2009, both reviewed in the next section). In order to analyse the impact of sound on different types of workers, Mak & Lui (2012) have divided the respondents into two groups - 'high' and 'low' productivity, compared to the mean productivity of the study population – however all the productivity data are also obtained through self-assessment. The study's findings are not sufficiently supported by factual data to permit clear conclusions, as no environmental measurements or objective performance data were collected.

IAQ: INDOOR AIR QUALITY

Four articles included in the review addressed aspects of indoor air quality (IAQ) and performance.

Rahman et al. (2014) have studied the effect of air quality on work performance by using questionnaire data obtained from 20 respondents working in a mechanically ventilated academic office building located in Malaysia. One of the survey questions asked respondents to rate the relation between air quality (conceptualised as temperature, humidity and air velocity) and their work performance (comprised of *Motivation, Ability, Quantity, Quality, Timeliness*) using a 1 to 5 rating scale. Of the three air quality components, temperature had the strongest correlation with work performance – high temperature affected working ability negatively.

The effects of increasing the ventilation rate from 5 to 10 and 20 l/s per person on productivity have been tested by Park and Yoon (2011) in an laboratory experiment with 24 participants aged 21 to 30. The air quality had been deliberately polluted by the introduction of typical sources of air contamination for office spaces – new carpets, furniture and finish materials. The experiment was conducted over a three-week period, with participants performing the same 'office-type' tasks for three consecutive days each week: *addition test, the Stroop test, proof reading,* and *typing*. Each session was eight-hours long, with a lunch and refreshment break. Participants were encouraged to adjust their clothing in order to maintain thermal comfort throughout the day, however they were unaware of the change in ventilation rate. Researchers monitored temperature, humidity, noise and light levels (all were maintained relatively constant during the experiment), CO2 concentration, airborne particulate matter (PM_{10}), formaldehyde and total volatile organic compounds (TVOCs) content. The highest average concentration of air pollutants was recorded at the lowest ventilation rate of 5l/s per person. Results showed that the change of ventilation rate from 5 to 20 l/s per person had a significant positive effect on the overall performance of the participants leading to a 2.5 - 5% increase, however this includes uncertainties brought by the learning effect, as work was repeated by the participants. Differences were found between performance levels on different types of tasks: the increase of accuracy on the addition, text-typing, and memorisation tasks was registered at higher ventilation rates (highest at 20 l/s per person), and a similar tendency was found for text-typing and memorisation.

Šeduikyte and Bliūdžius (2005) also researched the effects of air pollutants emitted by building materials on air quality perception and performance, using an experiment with 24 participants aged 19-29. The simulated office environment was ‘low polluting’ (i.e. the presence of air pollutants was controlled) and had controlled conditions of 24°C and 50% RH. Three conditions were tested: 3 l/s per person ventilation rate with outdoor air (with bioeffluents present); 3 l/s per person with introduction of an air pollution source (a carpet); 20 l/s per person with no air pollution source. Similarly to Park & Yoon (2011), the study found a positive relationship between increased ventilation rate and performance on the two-digit addition task, and text typing was also significantly faster at 20 l/s per person. However, no information is offered by the authors about the duration of exposure to the different ventilation rates, which may act as a limitation of the study’s validity.

Bogdan et al. (2012) investigated the effects of personalised ventilation systems on worker productivity. These systems (which heat or cool the supply air) allow users to control their local thermal environment. A climate chamber experiment was conducted on a population of 20 male participants of average age of 22.4 years. The chamber was equipped with a desk with two air diffusers (at face and ankle level, respectively) and a personalised ventilation system that heated or cooled the outdoor air and used the two air diffusers at a ventilation rate of 20 l/s and 0.8 m/s air velocity. There were two sessions of 40 minutes each. In the February session, the ambient temperature of the chamber was set to 20°C and 22°C, with the supply air set to 1°C or 2°C higher, while in May the ambient temperature was 26°C and 28°C and the supply air temperature 1°C or 2°C lower. Participants' performance was assessed using 3-minute *Concentration* and *perception tests* (speed, number of omissions and mistakes was measured). Participants' mental load was measured using a self-report scale addressing aspects of *fatigue* and *mood*. Results showed that in the February session, the highest level of performance was at 20°C ambient temperature and 21°C face or ankle-oriented air supply; the best fatigue and mood ratings were obtained at 20°C ambient and 22°C face or ankle air supply temperature. Yet, at 22°C ambient temperature, the *preferred* personalised ventilation temperature was 1°C higher. For the May session, the highest performance was found at 28°C ambient and 1 or 2°C lower face-oriented air supply. The best fatigue and mood ratings were noted at 26°C ambient and 24°C face-oriented air supply. These findings suggest optimum performance and thermal neutrality may not always coincide.

ACOUSTICS

Three articles included in the review explored the effects of acoustics on productivity or performance.

While auditory distraction within the office has multiple sources, two articles (Kaarlela-Tuomaala et al. 2009; Haka et al. 2009) focused on the impact of irrelevant background speech on task performance and subjective disturbance related to the acoustic environment. Both studies tested the impact of Speech Transmission Index (STI). STI is a standardised measurement commonly used to assess speech intelligibility, for instance STI = 0.5 indicates that 50% of the syllables are correctly heard. According to Kaarlela-Tuomaala et al. (2009), maximum task performance is achieved in the absence of speech (STI=0), and performance decreases at STI=0.3 (or STI=0.2 according to Haka et al. 2009), reaching a low point at STI=0.60. In the STI range between 0.60 and 1.0 “it is very probable that performance is no longer affected because subjective speech intelligibility is perfect” (Kaarlela-Tuomaala et al. 2009: 1429). The studies also considered the variability of Sound Pressure Level of speech (SPL), measured in decibels (dB).

Kaarlela-Tuomaala et al. (2009) conducted a longitudinal study before and after the relocation of an engineering and maintenance services company from private 10 m^2 cellular offices to a 200 m^2 open plan office. The authors explored the effects of the perceived acoustic environment on the self-rated performance of 31 employees. Participants (26 to 56 years old, mean age 35) completed a sixteen item questionnaire two months before and four months after the relocation; the questionnaire collected perceptions of indoor environmental conditions, with particular focus on acoustics. Additionally, STI and SPL of speech were measured before and after the move. The study found that the average noise level (time-averaged SPL of the working day) did not change significantly after the move to the open plan layout, but the variability of noise was lower in the open-plan office. STI values recorded in the open-plan offices between adjacent workstations (0.76) were also much higher than the STI of the adjacent private offices (0.42 when doors were open). Questionnaire results showed that in the open-plan office, irrelevant noise was perceived as more disturbing than in the cellular office condition with speech (voices and laughter) being perceived as the most distracting. Concentration problems were signalled more frequently after the move, particularly in relation to mathematical tasks, billing, statistics, and telephone discussions. The study offers valuable insights on the acoustic problems of two common office types. However, the lack of objective performance measures, the relatively small sample, and, possibly the timing of the data collection schedule (four months might not be sufficient for workers to adapt to the new workspace) act as limitations.

Haka et al. (2009) examined the impact of STI on cognitive performance in a laboratory experiment with 37 university students aged between 18 and 39 (mean age =23). The experiment was conducted in an environmentally controlled 30 m² room. Three speech conditions were tested: STI=0.1 (typical for a private office), STI=0.35 (“acoustically excellent open office”), and STI=0.65 (“acoustically poor open office”), while the SPL was maintained constant at 48 Db (Haka et al. 2009: 456-7). To test the impact of STI on performance, researchers used questionnaires and cognitive tasks performed in three sessions of approximately 50 minutes each. Questionnaires included items related to the introversion, trait anxiety, and noise sensitivity of participants, and assessed subjective perceptions of the speech conditions, state anxiety and alertness. Based on their sensitivity to noise and introversion, participants were divided into two groups (n=19; n=18) and asked to perform several cognitive tasks:

- The *Number series task* required verbal processing and working memory;
- The *Operation span task* - verbal processing, working memory and learning;
- The *Dot series task* - spatial awareness and working memory;
- The *Reading comprehension task* was indicative of the subjects’ learning, logical thinking, working memory, long-term memory, and semantics;
- The *Proofreading task* - orthographical and semantic processing.

The study found no significant differences between performance under the two lower STI value conditions, which challenges the assumption that performance drops at STI values higher that 0.2 or 0.3. However, under the STI=0.65 conditions, performance was significantly reduced for the number series task and operation span task; contrary to expectations, no significant effects were found for the semantically oriented tasks. Subjective ratings of the disturbance of speech and sound level increased proportionally with the STI value. Self-rated efficiency also significantly decreased as STI values increased. The study offers valuable insights of the impact of speech on cognitive performance, derived from objective measures and subjective evaluations. It suggested that irrelevant speech might affect some cognitive domains more than others, which was also shown by Kaarlela-Tuomaala et al. (2009). However, one of its limitations may be the demographic characteristics of the population, who are not necessarily representative of the workforce

The effects of office noise and *restoration* have been studied by Jahncke & Halin (2012) in a 2 x 2 factorial laboratory experiment on a sample of 38 individuals of 20 to 65 years old, 20 of whom (mean age = 53) had a hearing impairment, and 18 had normal hearing (mean age = 48). The within-participant factor was noise, i.e. recordings of a real life open plan office, set to ‘low’ and ‘high’ levels for this experiment (equivalent to 30 and 60 dB). The 63 m^2 environmentally controlled laboratory was designed as a neutral, open-plan office. Participants attended three experimental sessions under different noise conditions, during which they were asked to perform different cognitive tasks: *maths, word memory, reading comprehension, search tasks, and serial recall*; subjects also rated their level of sleepiness and motivation. After completing tasks under different noise conditions for two hours, the subjects were exposed to a restoration period for 14 minutes. Physiological stress indicators were also measured: *catecholamine concentration* traced from urine samples collected pre work (before the start of the session), mid work (after 1 hour 30 minutes) and post rest (after 3 hours) and *cortisol levels*, traced from saliva samples gathered pre-work, mid-work (after 1 hour), post work and post rest. Contrary to the hypothesis, the study found no significant effect of noise on the overall performance on math, reading, search task and serial recall tasks. However, hearing impaired participants performed worse than the normal hearing participants in word memory tests, possibly because of their higher sensitivity to noise. Interestingly, normal hearing participants performed better under high noise conditions, possibly because of their motivation and arousal levels. Similarly, in their investigation of temperature and cognitive performance, Lan et al. (2009) also found that performance was maintained even in unpleasant conditions, if subjects were motivated to complete the task. No significant effects of noise were found on stress hormones, or on self-rated fatigue and physiological markers showed no restorative effect. The methodology's robustness is given by the combination of objective performance data, physiological measures, and insights obtained from subjective evaluations, however the results were insufficient to support any of the study hypotheses. The sample size was probably insufficient to support the 2 x 2 factorial design. Furthermore, some of the study design features (e.g. short duration of the experiment, the hours when the sessions were held – from 4 to 7 pm) may have unintentionally affected the measured outcomes.

Many of the studies included in this and the previous section demonstrated new ways of obtaining objective measures of productivity and performance for intellectual work, by relying on cognitive and /or physiological determinants. However, cognitive testing in laboratory experiments is limited to relatively small sample sizes and usually only a small number of variables can be monitored.

LAYOUT AND DESIGN

Three articles explored the effects of layout and design on productivity or performance.

Peponis et al. (2007) analysed the implications of workplace design and spatial layout on the productivity of 50 knowledge workers from a communication design organisation who had relocated to new premises by using two main analytic tools: *space syntax*, and *social network analysis.* Before the move, the 1672 m^2 layout allocated 70% of the space to individual workstations and 30% to shared spaces, while in the 'new' 1486 m^2 space, only 55% was individual space. Researchers used *space syntax* analysis to create a quantitative description of the physical office layout, for both the old and new office layouts. This included circulation analyses, and visibility polygons drawn to measure "all areas that can be accessed in an uninterrupted straight line of movement from a point of origin"(Peponis et al., 2007: 831). *Social network analysis* was used to identify the patterns of communication between employees i.e. the patterns of organisational behaviour. Questionnaires gathered the employees' perceptions on Access and Interaction - they were asked to identify those with whom they interact and the frequency of the interaction. The impact of the design on productivity was analysed based on the precise nature of the company's work patterns – using project billing data from an admittedly small sample size of projects provided by the company before and after the move. The results of the study suggest that "the syntax of the spatial relationships of a setting provides an important underlying structure within which [cognitive] processes can become stable" (Peponis et al., 2007: 837). The space analysis showed the new premises were better connected and integrated, which enabled the intensification of interaction after relocation, i.e. more people interacted on a frequent basis. While all these may be indicative of an increase in productivity for creative and group work, no evidence was presented for the routine work performed in the new premises. The study takes into consideration the physical implications of space layout and design supporting some aspects of knowledge work (informal communication through shared spaces), however it fails to demonstrate a quantifiable effect on the actual productivity of work, especially regarding routine, individual dimensions of work.

Robertson et al. (2008) have conducted an intervention study exploring the impact of 'flexible workspaces' and ergonomics training on the psychosocial work environment, musculoskeletal health, and work effectiveness on a sample of US management consulting firm employees working in an office setting. Workers were assigned to one of the following conditions: flexible workspace (WS group, n=121), flexible workspace and ergonomics training (WS+T group, n=31), or no intervention (control group, n=45); no demographic information was collected:

- The flexible workspace condition referred to the introduction of adjustable workstations, a variety of meeting rooms and the increase of the office layout flexibility.
- The ergonomics training was conducted in a way that encouraged employees to exert *control* over the use of the workspace.

Data were collected two months before, and three and six months after the intervention. Electronic surveys were used to measure satisfaction with the workspace design, psychosocial work environment, body discomfort (for eight body parts), and work group effectiveness. Results showed that in both intervention groups, the positive perception of the following variables significantly increased: workspace, lighting, privacy, job control, collaboration, corporate culture, ergonomic climate, and communication. Reduction of work-related musculoskeletal discomfort was observed in the two groups as well, with the

WS+T group reporting a greater reduction. Building on business process analysis data, annual cost savings from the WS and WS+T groups were calculated at $7500 and $15,000, respectively, however it is unclear if the calculations were weighted according to the two very different sample sizes (121, and 31, respectively). The study builds on a clear approach, which offers valuable insights on the psychosocial aspects of the corporate workspace. Gathering data three times via a longitudinal study - with the third set of data collected at six months post-intervention - generated a more robust data set, which generally strengthens research findings. However, the fact that the three conditions have different sample sizes – the flexible workplace population is almost three times as numerous as the no-intervention group – and lack of demographic data limits the overall robustness of the conclusions.

Meijer, Frings-Dresen and Sluiter (2009) conducted a longitudinal study that analysed the short and long-term effects of an 'innovative' office intervention on the health and productivity of 138 workers of a Dutch Governmental institute The intervention was a full renovation of the office space, which replaced cellular workspaces with a open space layout with hot desking. The new office also implemented paperless policies and task-oriented use of space policies, encouraging workers to choose the work environment appropriate for the type of work performed. The new layout included tree main types of spaces:

- Concentrated working areas:
    - 'cockpit' workplaces with little openness and large distances between the workplaces
    - silent 'libraries' enclosed by glass walls;
    - 'coupe' workplaces with four desks.
- Teamwork areas characterised by openness and short distances between the workstations:
    - some included 'project tables' with computers and additional laptop places;

    - others designed as ‘lounges’ with sofas and desks;
    - ‘open’ workplaces with four grouped desks.
- Corporate areas for lunch breaks or other communal activities including a meeting room and a large ‘living room’ with tables and chairs per each floor.

Researchers used questionnaires completed pre-intervention, six and fifteen months post-intervention to measure baseline, short-term and long-term effects of the intervention. The questionnaires included self-assessments of: work-related fatigue (i.e. need for recovery after work); health (general health, change in health status, complaints of upper extremity musculoskeletal disorder, UEMSD); and perceived productivity (quality and quantity). Short-term results found no changes in perceived health, prevalence of UEMSD complaints or the perceived quality of performed work, while the perceived quality of work decreased, compared to the baseline values. The long-term results found no significant changes in perceptions of work-related fatigue, health, quantity and quality of work, compared to baseline conditions. However, significant changes were found. Perceived general health and productivity (both in terms of quantity and quality) had increased, while the prevalence of UEMSD complaints decreased. Based on long-term observation of subjective perceptions, the study’s method and findings may be useful for many companies experiencing the transition to new open-plan workspaces, however the addition of objective performance measures into the methodology of future research would be beneficial.

<u>INDOOR PLANTS</u>

Two articles presented the impact of indoor plants on worker performance.

Nieuwenhuis et al. (2014) have conducted three field experiments to compare the impacts of ‘lean’ (no indoor plants or decoration) and ‘green’ (indoor plants) office space on the employees' self-reported workplace satisfaction, concentration, air quality, productivity and engagement. The first study (N=67) used a questionnaire that gathered employees' perception of four constructs: workplace satisfaction, concentration, air quality, subjective productivity of the employees; respondents used a seven-point scale rating to answer the 8 questions. The second study (N=81) used a 14-questions questionnaire assessing Workplace satisfaction, Concentration, Air Quality and Disengagement, also using a seven-point scale. Furthermore, the second experiment also integrated objective productivity measurements: for 48 out of 81 participants, the company also provided average handling time (AHT) data, which takes into account the duration of the call, the hold-time and also the time it takes to report the details of the call into the system and switch on to a new call. The third study (N=33) asked participants to perform an information processing task. Generally, the studies indicated a positive association between green office space and the outcome variables (workplace satisfaction, perceived concentration and air quality, productivity, reported engagement), both in the short-term and long-term.

Bringslimark et al. (2007) have investigated the associations between indoor plants and various workplace outcomes using cross-sectional survey data obtained from 385 employees working within three workplaces located in large Norwegian cities. The physical features of the workplaces included individual and open plan spaces located in proximity to windows; plants of various heights were displayed throughout the spaces. Questionnaires gathered the workers' perception of the following variables: personal characteristics (gender); physical workplace factors (perceived disturbance from either noise, illumination, stale air, dry air, unpleasant smells, temperature, or static electricity); psychosocial workplace factors (job demands, control at work, and support from superiors and co-workers – none of which were controlled by the researchers). The survey also included questions related to perception of stress, productivity and sick leave. The study did not find unequivocal associations between indoor plant variables and perceived stress, however the number of indoor plants located in the workers' proximity had "small but statistically reliable" associations to sick leave and self-perceived productivity (: 585). The broad nature of the questionnaire, as well as the lack of any empirical data may act as limitations.

2.3.4. Methodological implications

The 34 articles included in the systematic review revealed several overall findings. Firstly, the low number of articles with social sciences scope included in this review shows that only few articles specifically addressed aspects related to the *physical dimensions* of the workspace. Similarly, in the articles with environmental sciences scope, *psychosocial dimensions* were only rarely addressed. **This suggests a knowledge gap between the two disciplines.**

Secondly, several observations can be made regarding the scope and terminology used by the 34 studies reviewed above. While article titles, abstracts or keywords refer to 'productivity' as being a study outcome, ***performance* is usually measured instead**. Almost twice as many articles measure performance (n=22) than productivity (n=12). Six studies included specific measures of wellbeing, which is operationalised differently, covering aspects related to mood, fatigue, job satisfaction or physical health; seven studies measured aspects of health. Examples of key **indicators used for measuring performance** include:

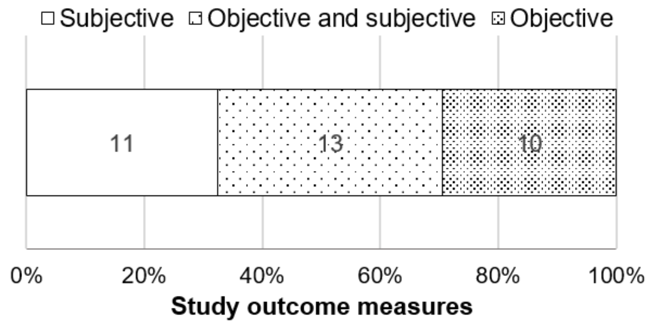
- **Subjective measures:**
  - Self-rated productivity / performance via questionnaires;
- **Objective measures:**
  - Cognitive task performance: Arithmetic, text typing, proofreading, working memory, verbal processing, learning, spatial awareness,

long-term memory, semantics.

- Neurobehavioural tests: Overlapping, Conditional reasoning, Spatial image, Memory span, Picture recognition, Visual choice, Letter search, Number calculation, Symbol–digit modalities test, Event sequencing, Reading comprehension, Graphic abstracting, Hand-eye coordination;
- Physiological markers of stress or brain activity: Heart rate variation, electrophysiological monitoring, Sulphatoxymelatonin, Neopterin;
- Computer work performance: Keystroke rate, Mouse activity, Minutes of computer use per hour;
- Estimations based on business process analysis (time, technology and personnel costs required by ongoing internal business processes).

Figure 2-7 shows the occurrence of subjective and objective measures used to measure productivity or performance. About a third each of the total number of studies used either subjective (n=11), or objective (n=10) measures, while the other third used combined measures (n=13).

Figure 2-7. Subjective and objective productivity / performance measures used by articles included in the systematic review



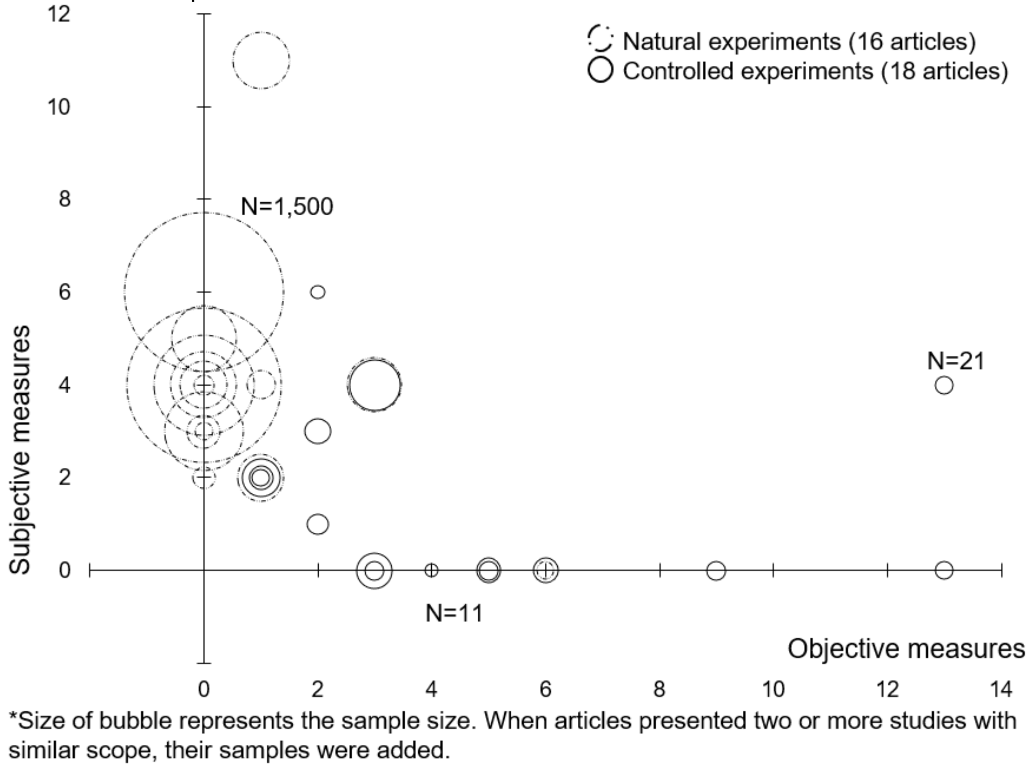
Thirdly, the review highlighted observations refer to the operational approach adopted by the studies. Two types of study design were used: natural experiments (‘field studies’, n=16, including five intervention studies[11], and one

[11] This review used the terminology deployed by the researchers to describe their studies. However, many of the ‘intervention studies’ may in fact be convenience samples taken from pre- post- studies of ‘natural’ experiments where the changes were determined by the organisation independently from the intention of studying their impacts.

EMA) and controlled experiments (n=18). Each have different consequences. Figure 2-8 displays the 34 studies as defined by their study design, the number of subjective and objective productivity / performance parameters they used, and their sample size. A summary of these dimensions is also presented in table 2-3 below.

As summarised in figure 2-8 and table 2-3 below, controlled experiments included in the review tended to use more objective performance parameters and have smaller sample sizes (between eleven and eighty). Furthermore, laboratory experiments were usually conducted over *shorter periods of time* compared to field studies (sometimes merely 40 minutes) which might limit the robustness of the findings. This observation is unsurprising: while laboratory conditions offer the advantage of controlling a considerable number of variables, the difficulties and costs of selecting a specific type of population and running the experiments limit both the duration and the number of participants.

Figure 2-8. Study types, subjective and objective measures of productivity/performance or its predictors, and sample sizes of the 34 articles included in the review.



*Size of bubble represents the sample size. When articles presented two or more studies with similar scope, their samples were added.

Perhaps more importantly, this suggests a conceptual approach to **productivity as a short-term effect determined almost completely by physical causes**. Some of the studies monitored physiological markers such as heart rate variation or brain activity. Single, or multiple predictor variables were considered:

- **Single input variables –** examples**:**
  - Temperature
  - Ventilation rate
  - Light colour temperature
- **Multiple input variables –** examples:
  - Temperature and humidity
  - Temperature and air quality
  - Temperature, air quality and ventilation rate
  - IEQ – various definitions
  - Font size and glare.

Further limitations to this approach include the 'Hawthorne effect' mentioned earlier in section 2.2.2., i.e. participants' motivation to perform well when being under observation. This may explain counter-intuitive effects found when participants were able to maintain their performance even under unpleasant thermal conditions (for example Lan *et al.*, 2009).

In contrast, field studies (presumably) offer the advantage of accessing a wider sample of the targeted office worker population (between 19 and 1500, with most studies above 100 participants), and the opportunity to consider more variables in real world settings. These studies rely on subjective metrics with *perceived* performance or productivity being just an aspect of a wider scope of research. Many of the studies are intervention studies exploring the effects of a move to new premises, conducted over longer periods of time pre- and post-intervention. This suggests that **productivity is seen as a long-term phenomenon influenced by physical and psychosocial factors**.

Table 2-3. Systematic review of evidence-based workspace productivity and wellbeing articles: Summary of findings

No	Reference	Study design	Predictors	Outcomes	Outcome measure(s)	Objective measures	Sample size
1	Haynes (2008)	Natural experiment	Comfort, layout, interaction, distraction	Productivity	Subjective		996 / 422
2	Kwallek et al. (2005)	Controlled experiment	Interior colour schemes	Perfomance and Job satisfaction	Objective and subjective	Task performance (details undisclosed)	90
3	Knight and Haslam (2010)	Controlled experiment	Managerial control of space	Performance and wellbeing	Objective and subjective	Task performance: card sorting task, information management and processing, vigilance task; organizational citizenship behaviour.	112 / 47
4	Valančius and Jurelionis (2013)	Controlled experiment	Temperature	Performance	Objective	Task performance: arithmetic, text typing, Tsai-Partington test	78
5	Kekäläinen et al. (2010)	Natural experiment: Intervention	Temperature	Performance	Objective and subjective	Task performance: arithmetic and data processing	118 (133)
6	Tanabe, Nishihara and Haneda (2007).	Controlled experiment	Temperature	Performance and fatigue	Objective and subjective	Physiological markers Task performance: arithmetics	40
7	Lan et al.(2009).	Controlled experiment	Temperature	Performance	Objective	Task performance: overlapping; conditional reasoning; spatial image; memory span; picture recognition; visual choice; letter search; number calculation; symbol–digit modalities test	24
8	Lan and Lian (2009)	Controlled experiment	Temperature	Performance	Objective	Task performance – the nine tests used by Lan et al. (2009) and: event sequence; reading comprehension; graphic abstracting and hand–eye coordination;	21

Table 2-3. Systematic review of evidence-based workspace productivity and wellbeing articles: Summary of findings (continued)

No	Reference	Study design	Predictors	Outcomes	Outcome measure(s)	Objective measures	Sample size
9	Lan et al. (2010)	Controlled experiment	Temperature	Performance and wellbeing	Objective and subjective	Physiological markers Task performance: the13 tests used by Lan and Lian (2009)	21
10	Tsutsumi et al. (2007)	Controlled experiment	Temperature and relative humidity	Performance and fatigue	Objective and subjective	Task performance: Text typing, arithmetic Physiological markers	12
11&12	Kim and Kim (2007a,b)	Controlled experiment	Light and lighting	Performance	Objective and subjective	Task performance: Letter identification task	36
13	Mills et al. (2007)	Natural experiment: Intervention	Light and lighting	Performance and wellbeing	Subjective	-	69
14	Wei et al. (2014)	Natural experiment: Ecological momentary assessment	Light and lighting	Productivity, health, wellbeing	Subjective	-	26
15	Ko et al. (2014)	Controlled experiment	Light and lighting	Performance	Objective and subjective	Task performance: visual search and matching	27
16&17	Hoffmann et al. (2008, 2010)	Controlled experiment	Light and lighting	Performance and wellbeing	Objective	Physiological markers Task performance	11
18	Feige et al. (2013)	Natural experiment	IEQ: Indoor environmental quality	Productivity, health, wellbeing	Subjective	-	1,500
19	Hedge & Gaygen (2010)	Natural experiment	IEQ: Indoor environmental quality	Performance	Objective	Computer work performance: Keystrokes and mouse-clicks per minute	19
20	Menadue et al. (2013)	Natural experiment: Intervention	IEQ: Indoor environmental quality	Productivity, health, satisfaction	Subjective		600
21	Singh et al. (2010)	Natural experiment: Intervention	IEQ: Indoor environmental quality	Productivity and health	Subjective		263
22	Mak and Lui (2012)	Natural experiment	IEQ: Indoor environmental quality	Productivity	Subjective		259

Table 2-3. Systematic review of evidence-based workspace productivity and wellbeing articles: Summary of findings (continued)

No	Reference	Study design	Predictors	Outcomes	Outcome measure(s)	Objective measures	Sample size
23	Rahman et al. (2014)	Natural experiment	IAQ: Indoor air quality	Performance	Subjective		20
24	Park and Yoon (2011)	Controlled experiment	IAQ: Indoor air quality	Performance	Objective	Task performance: arithmetics, typing, proof reading, the Stroop test	24
25	Šeduikyte and Bliūdžius (2005)	Controlled experiment	IAQ: Indoor air quality	Performance	Objective	Task performance: arithmetics, typing	24
26	Bogdan et al. (2012)	Controlled experiment	IAQ: Indoor air quality	Productivity and mental load	Objective and subjective	Task performance: concentration and perception test	20
27	Kaarlela-Tuomaala et al. (2009)	Natural experiment: Intervention	Acoustics	Performance	Subjective		31
28	Haka et al. (2009)	Controlled experiment	Acoustics	Performance	Objective	Task performance: working memory,verbal processing, learning, spatial awareness, long-term memory, semantics.	37
29	Jahncke and Halin (2012)	Controlled experiment	Acoustics	Performance	Objective	Task performance: arithmetics, word memory, reading comprehension, search tasks, and serial recall Physiological markers	38
30	Peponis et al. (2007)	Natural experiment: Intervention	Layout and design	Productivity	Objective and subjective	Estimations based on previous projects billing data	50

Table 2-3. Systematic review of evidence-based workspace productivity and wellbeing articles: Summary of findings (continued)

No	Reference	Study design	Predictors	Outcomes	Outcome measure(s)	Objective measures	Sample size
31	Robertson et al. (2008)	Natural experiment: Intervention	Layout and design	Productivity, health, psychosocial workplace	Objective and subjective	Estimations using business process analysis (time, technology and personnel costs required by ongoing internal business processes)	197
32	Meijer, Frings-Dresen and Sluiter (2009)	Natural experiment: Intervention	Layout and design	Productivity and health	Subjective		138
33	Nieuwenhuis et al. (2014)	Natural experiment	Indoor plants	Productivity and engagement	Objective and subjective	Average handling time (AHT) of call Task performance: Information processing	68 / 81 / 33
34	Bringslimark et al. (2007)	Natural experiment	Indoor plants	Productivity and health	Subjective		385

2.4. Update of literature review: Biophilia and further reading

The systematic review of literature presented in the previous section adopted a strict method, and as a result, several important aspects relating to workspace productivity and wellbeing were missed. This section extends the scope of the review by incorporating literature from reputable sources within and beyond the academia, most of which were published since 2014.

2.4.1. Biophilia

The impact of buildings on occupant health has been brought to the forefront by organisations active in the research, development and communication of best practices in the built environment and sustainability. As mentioned before, examples include comprehensive research from the World Green Building Council (WGBC, 2014), the BCO '*Wellness Matters*' investigation (2018), the WELL® Building Standard (International WELL Building Institute, 2015) and the Fitwel® Rating System (Center for Active Design, 2018). These initiatives highlight the importance of meeting the physiological demands of health and comfort associated with optimum functioning. This includes ***Biophilia*** **- the innate attraction towards life and lifelike processes and natural habitats**, a concept coined by Harvard biologist E.O. Wilson (Wilson, 1984/2003).

According to BCO's '*Wellness Matters'* Biophilia can be sustained within the built environment directly or indirectly through:

> "Materiality, gardens and allotments, water features, sounds from nature, views out of the building to nature or within to internal gardens, static and moving images" (BCO, 2018: 79).

Evidence gathered in recent works generally supports the idea that Biophilia is associated with psychological and physiological benefits. Several examples are discussed below

Cooper and Browning (2015) investigated **the impact of biophilic design on office workers' wellbeing and productivity** across the globe in a study entitled *'Human Spaces: The Global Impact of Biophilic Design in the Workplace'*. The study used online surveys to collect self-assessments of workspace characteristics and preferences, wellbeing and productivity in the previous three months. Wellbeing was conceptualised as a combination of feeling 'happy', 'inspired' and 'enthusiastic'. The sample included 7,600 office workers across a variety of sectors and roles. Respondents were based in 16 countries: "United Kingdom, France, Germany, Netherlands, Spain, Sweden, Demark, United Arab Emirates, United States, Canada, Brazil, Australia, Philippines, India, China and Indonesia" (: 8). Global results of the study include:

- 47% of respondents worked in offices that did not provide natural light. The countries with the highest proportion of workers who did not have natural light in their workplace were the UK (66%) and the US (64%).
- 58% did not have any plants in their workplaces, and 19% indicated a complete lack of natural elements in the office.
- 39% of respondents thought they were most productive as assigned desk in private offices, and 36% of the sample felt most productive when using assigned desks in open plan offices.

The study also highlighted workers' clear preference for biophilic design elements in their workplace: two thirds of the sample (67%) reported feeling happy in "bright office environments accented with green, yellow or blue colors". (all three colours are frequently found in most natural environments). The top five office design elements that workers desired the most were: natural light (most important, 44%), indoor plants (20%), quiet working space (19%), view of the sea (17%), bright colours (15%). Self-reported productivity was also positively associated with the presence of biophilic elements in the workspace: people who worked in spaces with nature views and accent colours. Associations were also found between wellbeing and biophilic design elements: workers who used office spaces with natural elements such as plants and daylight reported 15% higher levels of happiness compared to those who had no biophilic elements in their offices. This is summarised in table 2-4 below:

Table 2-4. Biophilia and Wellbeing findings. Adapted from Cooper and Browning (2015: 17)

The table below presents the percentage of respondents (N=7600) that report feeling happy, inspired, anxious or bored when entering workplaces that either do or not provide internal green spaces.

How do you feel when you enter the workplace?		Internal Green Space	
		Yes	No
Positive feelings	Happy	15%	9%
	Inspired	32%	18%
Negative feelings	Anxious	2%	5%
	Bored	5%	11%

The strength of these implications is enhanced by the large and geographically diverse sample of the '*Human Spaces'* study. However, little information is presented about possible confounders of the relationship between the elements of the relationship being investigated. Demographic elements such as occupation could impede on wellbeing: workers in senior roles may have access to better or more pleasant working environments - e.g. with natural views, and/or designed to a higher quality standard. Also, the inclusion of objective measurements of physiological responses to the parameters under investigation would have strengthened the methodology even further.

Yin et al., (2018) adopted a different methodology in a study that explored the **physiological and cognitive performance of exposure to biophilic indoor environments** on a sample of 28. A randomised crossover study design was adopted. Participants spent time in spaces that included biophilic elements, and with no such features, while wearable sensors measured their blood pressure, galvanic skin response and heart rate. Cognitive tests were administered at the end of each testing session. Sessions lasted one hour and included physical and virtual exposure to the environments while sitting down. Two similarly sized rooms were used, of which one included a bamboo floor, plants, and views of a river and green space with indoor plants (‘biophilic’), and the other had no windows or plants (‘non-biophilic’). Physical exposure required participants to observe the environment directly, while virtual exposure involved watching pre-recorded “immersive 360-degree field-of-view videos (: 257) of the same space using virtual reality headsets. After each randomly ordered scenario, participants completed three tests that measured different aspects of cognitive functioning. Before and after each complete session, participants’ emotional states were measured using self-report surveys.

Results showed exposure to the biophilic environments was associated with most outcomes of the study. In the biophilic condition, participants had significantly lower blood pressure and skin conductance levels. Their cognitive functioning was also better: participants in the biophilic condition scored 14% higher than those in the non-biophilic condition. Emotional effects were also observed: when experiencing the biophilic environment, participants “reported lower stress and frustration levels, higher engagement and excitement level” compared to their answers in the non-biophilic space. Interestingly, no difference was found between the physical and virtual exposure, for any of the three outcomes: virtual exposure to biophilic environment was just as impactful as physical exposure.

The robust methodology employed by the researchers and the unique approach that combines physiological, cognitive and emotional measures strengthens these findings. This study also used new technologies – **wearable**

biometric devices and virtual reality. However, future work on a larger sample would strengthen it even further.

2.4.2. Further reading

Additional articles that were potentially relevant to this work have been published in the 2015-2019 period. This was a relatively fertile period for research, particularly related to the built environment and cognitive performance (taken as a proxy for productivity), health and other outcomes.

A considerable number of academic articles investigated the effects of physical activity and standing. Graves *et al.*, (2015) investigated the effects of sit-stand desks on sitting time, and behavioural, cardiometabolic and musculoskeletal outcomes using an ecological momentary assessment method. Similarly, Baker *et al.*, (2018) studied the effects of prolonged standing on musculoskeletal comfort and cognitive function. Fisher *et al.*, (2018) studied the associations between office layout and sitting time and activity levels.

Other articles focused on the relationship between air quality and ventilation and health (Carrer *et al.*, 2015 conducted a review of evidence) or cognitive function (Allen et al., 2016). Steinemann, Wargocki and Rismanchi, (2017) explored the relationship between green buildings and indoor air quality.

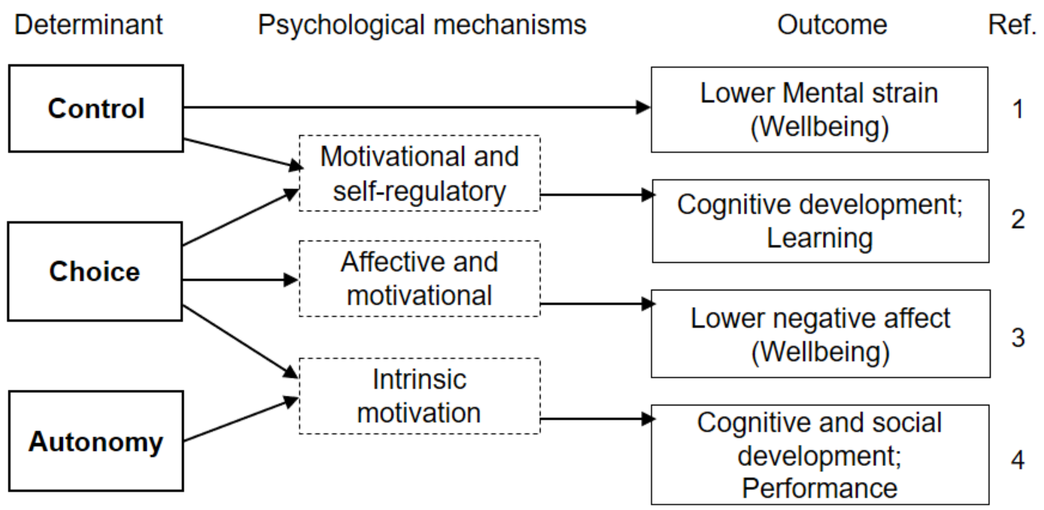
Some valuable reviews of literature related to office workplaces and productivity have been published such as Bortoluzzi *et al.*, (2018), Carrer *et al.*, (2015), Appel-Meulenbroek, Clippard and Pfnür, (2018)

These articles - and other similar to them - were consulted but not reviewed in full detail here. They are included in the 'Further reading' section of the thesis.

2.5.The 'Workplace': Psychosocial determinants of productivity and wellbeing - Review of literature

The previous section showed that evidence-based research on workspace productivity and wellbeing conducted in the recent decade tends to focus primarily on their physical – or physiological – determinants. However, a different perspective exists on questions such as 'what motivates – and hinders - human development?', 'what enhances – and disrupts – personal growth?' - within and beyond the workplace. Several theories from psychology and sociology examine the role of *Choice, Control,* and *Autonomy* in motivating human development including, but not limited to, productivity and wellbeing (figure 2-9). The applicability of these ideas for workspace research were also discussed in a paper delivered at the International Facility Managers Associations (IFMA) World Workplace conference in 2016 (Hanc, 2016) and included in Appendix A (page 319). The following sections review the main theories associated to these constructs.

Figure 2-9. Control, choice and autonomy: Psychological processes



References:

1. Karasek (1979); Karasek and Theorell (1990) 2. Bandura (1987, 2000, 2012)
3. Leotti et al (2010) 4. Ryan and Deci (2000;2008)

2.5.1. Choice and self-efficacy

The Social Cognitive Theory (SCT), developed by Stanford University

Professor Albert Bandura (1986; 1997), is founded on an agentic perspective[12] of human functioning – i.e. development, adaptation and change. A core component of SCT's perspective on human agency is *self-efficacy*, considered to be central to human functioning:

> "Among the mechanisms of agency, none is more central or pervasive than beliefs of personal efficacy. Unless people believe they can produce desired effects by their actions, they have little incentive to act…Perceived self-efficacy refers to beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (Bandura, 1997: 3).

People's beliefs in their own capability to exercise (some degree of) control over their own functioning and environmental events "affect the quality of human functioning through cognitive, motivational, affective, and decisional processes" (Bandura, 2012: 13). They play a "pivotal role" in people's "self-regulation of emotional states" (: 13). Beliefs of self-efficiency motivate people to act and persevere when faced with difficulties, or in self-debilitating ways (pessimistic thinking, vulnerability to depression and stress). Crucially, beliefs of self-efficiency contribute to self-development, via the role of choice processes:

> "By their choices of activities and environments, people set the course of their life paths and what they become." (Bandura, 2012: 13).

The applicability of the SCT theory to the workplace context has been explored by a growing number of studies in recent decades. Fan et al. (2013) developed the 'workplace social self-efficacy' (WSSE) Inventory, a scale

[12] "To be an agent is to intentionally make things happen by one's actions. Agency embodies the endowments, belief systems, self-regulatory capabilities and distributed structures and functions through which personal influence exercised, rather than residing as a discrete entity in a particular place" (Bandura, 2001)

comprised of 22 items related to social gathering, performance in public contexts, conflict management, and seeking and offering help. Paggi and Jopp (2015) studied the outcomes of occupational self-efficacy on 'older workers' on a sample of 313 employed adults aged 50 and older, finding associations with job satisfaction and life satisfaction.

2.5.2. Autonomy, Intrinsic Motivation and Self Determination

Ryan and Deci's Self-Determination Theory (SDT) is a macrotheory of human motivation, development and wellbeing, which proposes the existence of three basic psychological needs – the need for *autonomy, competence, and relatedness* - that facilitate (or hinder) people's "natural propensities for growth and integration, … for constructive social development and personal well-being." (Ryan and Deci, 2000: 68). SDT distinguishes between two types of motivation leading to very different - possibly opposite - effects: autonomous and controlled motivation (Deci and Ryan, 2008).

A core construct of autonomous motivation is intrinsic motivation, or the "natural inclination toward assimilation, mastery, spontaneous interest, and exploration that is so essential to cognitive and social development" (Ryan and Deci, 2000: 70), which is enhanced by *choice, feelings of autonomy and opportunities for self-direction*. In contrast, controlled motivation equates to "pressure to think, feel, or behave", possibly leading to lower psychological health and less effective performance (Deci and Ryan, 2008).

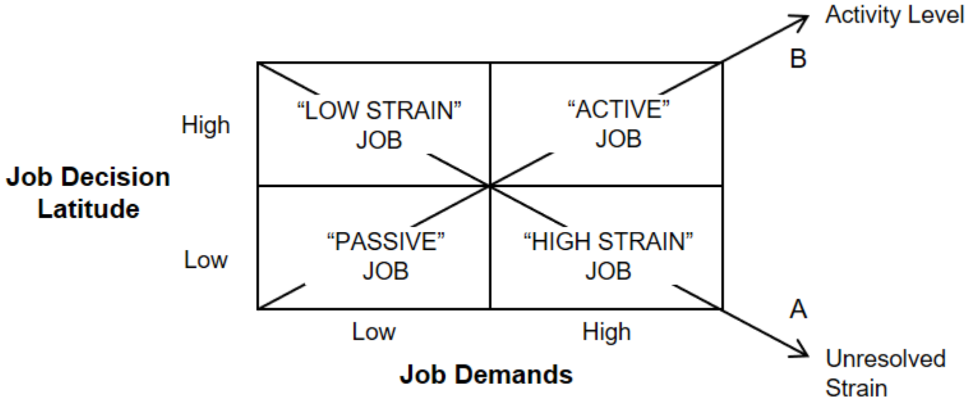
The differences between various types of motivation (or goals), their relationship to autonomy, and their outcomes have been explored by several studies. In a research experiment related to the workspace environment, managers' support of subordinates' autonomy was found to produce positive ramifications on employees' perceptions and satisfaction (Deci, Connell and

Ryan, 1989). Three field experiments conducted by Vansteenkiste et al. (2004) on high school and college students found that intrinsic goals and autonomy-supportive learning climates lead to higher learning, performance, and persistence outcomes than extrinsic goals and controlling environments. Furthermore, meta-analytic evidence from 41 studies revealed that choice enhanced intrinsic motivation and associated outcomes including task performance (Patall, Cooper and Robinson, 2008).

2.5.3. Job Control: The Job Demands-Control Model

In the workplace context, Karasek and colleagues (Karasek, 1979; Karasek and Theorell, 1990) postulated that **the combination of low decision latitude and high job demands is associated with mental strain and job dissatisfaction** (figure 2-10). Job decision latitude is understood as the "potential control over [one's] tasks and [one's] conduct during the working day", (1979: 289).

Figure 2-10. Job strain model. Adapted from Karasek (1979: 288).



Since its development, the model – and its subsequent variations - was widely used in workspace research. Examples include explorations of health risks of Swedish 'white collar' workers (n=1,937) which revealed high job control was associated with lower coronary heart disease, absenteeism, and depression (Karasek, 1990). Similarly, Fox, Dwyer and Ganster (1993) studied the effects of job demands and control on physiological outcomes in hospital settings (n=136), indicating support for the model.

2.5.4. Choice as a vehicle for perceiving control

Choice may act as a vehicle for *perceiving* control, which makes it effective even in situations where actual control over events is absent. Leotti, Iyengar, & Ochsner (2010) propose that choice is generally desirable, as it “allows organisms to exert control over the environment by selecting behaviours that are conducive to achieving desirable outcomes and avoiding undesirable outcomes” (Leotti et al., 2010), whereas restriction of choice is aversive. Perception of control, suggest Leotti and colleagues, is “adaptive across diverse spheres of psychosocial functioning” (Leotti et al., 2010), and is implicated in regulating emotional responses to various situations – for instance in stressful situations, it may modulate emotion by reducing negative affect. This was explained by the effect of choice over the two interconnected areas of the brain implicated in both affective and motivational processes – the prefrontal cortex (PFC) and the striatum – specifically the fact that choice uses the same neural circuitry. Thus “choice in itself may be inherently rewarding” (Leotti et al., 2010). Elsewhere, Leotti and Delgado (2011) have supported this hypothesis through a study using functional magnetic resonance imaging (fMRI).

2.5.5. Control over the built environment

The theories cited earlier in this section allocate little importance to the physical parameters of the environments within which life – and work – take place. They use the term ‘workplace’ in a mostly psychosocial sense which excludes any potential roles of the built environment, i.e. the ‘workspace’. However, control over the built environment – or the “mastery or the ability to either alter the physical environment or regulate exposure to one's surroundings" (Evans and Mitchell McCoy, 1998) - has been suggested by some to affect human wellbeing and functioning. According to Evans and Mitchell McCoy (1998) environmental elements designed for "stimulation, coherence, affordance, control, and restoration" – are proposed to be "inter-related to stress". Privacy – the ability to regulate the dynamics of social interaction - may contribute to the sense of control over the built environment.

Findings from the research literature often suggest that control is an important element in the workspace. A study conducted in office settings found links between environmental control, higher environmental satisfaction and lower psychological stress (Huang et al., 2004). A similar study found that perceived environmental control increased group cohesiveness and perceived performance (Lee and Brand, 2005). Similarly, Knight and Haslam (2010) found that the managerial control of the workspace had effects on employees' satisfaction and wellbeing. Participants in the 'disempowered' office condition – i.e. whose personalised design of the experimental office settings were changed (overridden) by the researchers - reported low psychological and physical comfort.

2.5.6. The other side of choice

This literature reviewed so far in this section highlighted choice as an element associated with a variety of benefits. However, this is not unanimously accepted. This section briefly discusses a few views that object to choice as an universally positive – or even, real – construct.

Choice, autonomy, and other associated concepts (such as 'free will') may be culturally determined. Most Western cultures – where 'the customer is always right', 'beauty is in the eye of the beholder', and 'listen to your heart' slogans are well established – glorify *humanism*, the human-centric paradigm (Harari, 2017). But in this world, where the individual has so much freedom, there is much pressure to make the *right* choice.

American psychologist Barry Schwartz writes about '*The paradox of choice*' (2004): the more choice we have, the harder it is to commit to one, for fear of 'missing out'. This often triggers anxiety, regret and unhappiness. Sheena Iyengar and Martin Leper conducted three experimental studies highlighting the demotivating aspects of choice (Iyengar and Lepper, 2000). Participants from both field and laboratory studies were more likely to make a choice and they reported a greater level of satisfaction with the product when they were presented with *fewer* choices (six, instead of 24 to 30).

Finally, as shown by Yuval Harari's book 'Homo Sapiens' (2017) advances in neuroscience now make it possible to understand the human mind – which triggers everything from behaviour to the most intimate thoughts – as a result of electrochemical events in the brain. It may be, he argues, that 'free will', a construct closely associated with choice, may not exist after all:

> "Decisions reached through a chain reaction of biochemical events, each determined by a previous event, are certainly not free. Decisions resulting from random subatomic accidents aren't free either; they are just random. And when random accidents combine with deterministic processes, we get probabilistic outcomes, but this too doesn't amount to freedom" (Harari, 2017: 329)

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2.6. Wellbeing: Conceptual approaches and measures

In recent decades, initiatives and programmes led by intergovernmental organisations, policy makers, the academic community and various segments of the industry suggest the global interest in wellbeing is growing. While some of these initiatives take the form of cross-country or nation-wide programmes, others are focused on measuring wellbeing within specific contexts, such as buildings and office workspaces. The following section reviews some of these key initiatives.

2.6.1. Wellbeing or well-being: Definitions and associated concepts

There is no single commonly accepted definition of 'wellbeing' (or 'well-being' – the two spellings are used interchangeably). While the term is often used as a synonym to 'happiness', the definition provided by Oxford English Dictionary (OED) reveals additional complexity:

> "Well-being, *n*[13].
> With reference to a person or community: the state of being healthy, happy, or prosperous; physical, psychological, or moral welfare. With reference to a thing: good or safe condition, ability to flourish or prosper. In plural: Individual instances of personal welfare".(Oxford University Press, 2010d)

This definition reveals an array of possible dimensions. Some of these use concept that can perhaps be measured objectively, such as physical or psychological '*health'*, but others arguably pertain to the realms of subjective perception. While income can be quantified, the state of being '*prosperous*' may depend on individual or collective interpretations of the concept. Similarly, being '*happy*' or '*flourishing*' may bear considerably different meanings. Furthermore, the inclusion of the '*moral'* aspect adds another layer that is perhaps situated in between the objective and subjective realms, an ethical one.

As the term 'wellbeing' is often used interchangeably with 'wellness' -

[13] Noun.

albeit more commonly in American literature – it is perhaps worth exploring the additional meanings included in the OED definition:

> "Wellness, n.
> The state or condition of being well or in good health, in contrast to being ill; the absence of sickness; the state of (full or temporary) recovery from illness or injury. Spec. (orig. U.S.): As a positive rather than contrastive quality: the state or condition of being in good physical, mental, and spiritual health, esp. as an actively pursued goal; well-being".(Oxford University Press, 2010e)

While the general definition focuses on the specific dimension of being free from illness or injury ('*in good health*'), the U.S. specific definition reveals that 'health' can also be '*mental'* or '*spiritual'*. Interestingly, 'spiritual health' is defined as the active pursuit of wellness, which associates wellness with agency or intention.

As shown by these definitions, 'wellbeing' or 'wellness' and health are seemingly associated, which nevertheless suggests they are *distinct constructs*. However, the constitution of the World Health Organisation (WHO) adopted in 1946 suggests that 'health' *is* 'wellbeing':

> "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 2006/1946: 1)

A more recent definition on the WHO website adds:

> "Mental health is defined as a state of well-being in which every individual realizes his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community" (WHO, 2014).

Mental health is again defined as wellbeing, but several dimensions are specifically mentioned. The 2014 WHO update refers to the ability to 'realise one's potential', which may be similar to the 'flourishing' aspect included in the OED definition of wellbeing (2010d).

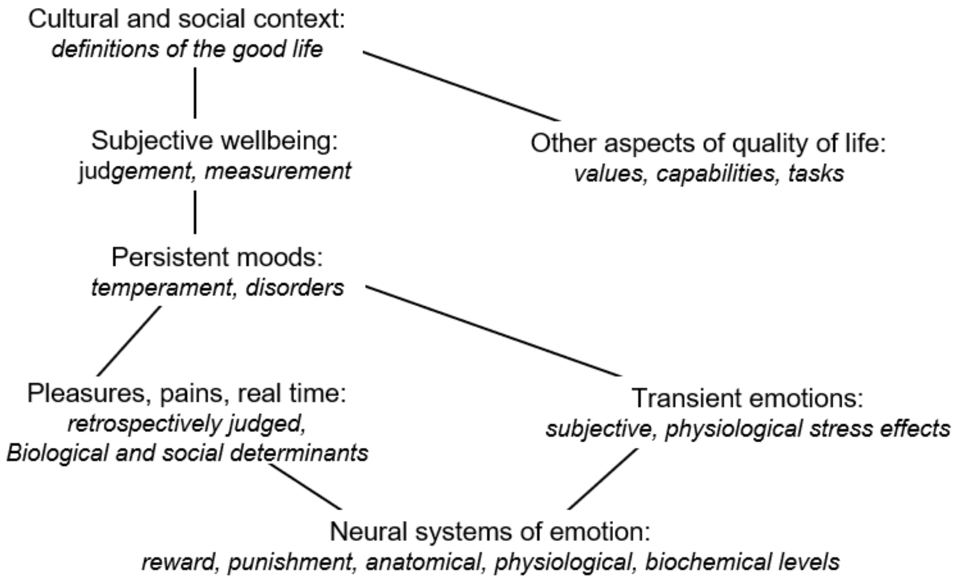
These definitions reveal the complex nature of wellbeing, and the difficulty of producing a single definition. Instead, three major perspectives have developed as distinct approaches in wellbeing research: Hedonic, Eudaimonic, and Social. The approaches are reviewed below.

(A) HEDONIC WELLBEING

Ryan and Deci (2001) provide an extensive review of two major traditions in the study of wellbeing: the Hedonic view and the Eudaimonic view. According to them, the Hedonic approach may have originated in an ancient philosophical view of happiness as 'pleasure' ('hedone' in Greek). Its meaning has since evolved considerably. Psychologists who adopt the hedonic view often conceptualise wellbeing as **subjective happiness**, which "concerns the experience of pleasure versus displeasure broadly construed to include all judgments about the good/bad elements of life" (Ryan and Deci, 2001: 144). Measuring the 'good life' is central to hedonism, and this is often the result of an ongoing 'pleasure' versus 'pain' conflict.

The authors of influential hedonic psychology volume '*Well-being: The Foundations of Hedonic Psychology'* (Kahneman et al., 1999) consider that the analysis of wellbeing consists of several levels (figure 2-11). The top level – quality of life – cannot simply be reduced to the pleasure versus pain dichotomy, but instead depends on the cultural determinants of what is considered 'a good life' an may include global indicators such as poverty or mortality rate. The next level down, subjective wellbeing, includes comparison to "ideals, aspirations, other people, and one's own past" (: x). Below this level is one of persistent states and traits which may be related to a person's characteristics or circumstances. Next, on the real-time level, pleasures and pains, and all other transient emotions are related to particular events or triggers. Finally, the neural systems level concerns the biochemistry of emotions. All these levels are arguably intertwined, and a deep understanding of human wellbeing should ideally consider all of them.

Figure 2-11. Levels in the analysis of the quality of life. Based on Kahneman et al. (1999: x)



In summary, Hedonic wellbeing equates happiness to general **satisfaction with life**, the presence of **positive moods** and feelings, and the absence of **negative moods.** Two of the most robust and widespread scales used to assess wellbeing (reviewed in the following sections) build on these concepts. The Satisfaction with Life Scale (Diener et al, 1985) addresses global life satisfaction, while the Positive And Negative Affects Schedule (Watson et al, 1988) echoes the 'pleasure'/'pain' dichotomy.

(B) EUDAIMONIC WELLBEING

While the hedonic view essentially equates wellbeing with happiness, a different perspective exists. As "not all desires—not all outcomes that a person might value—would yield well-being when achieved" (Ryan and Deci, 2001: 146), the eudaimonic view considers the two constructs as independent from each other. Drawing from Aristotle's views, *Eudaimonia* means living according to one's 'true self' (or 'daimon', in Greek), consistent with one's own values or principles. While the (often philosophical) pursuit of meaning in one's life may be pleasurable in itself, it may or may not lead to higher hedonic measures of happiness: the two are distinct types of experiences.

A comprehensive approach to the eudaimonic perspective on life is offered by Ryff and Keyes (1995). They redefine the concept of wellbeing as 'optimal functioning' as being comprised of six factors:

> "positive evaluations of oneself and one's past life (Self-Acceptance); a sense of continued growth and development as a person (Personal Growth), the belief that one's life is purposeful and meaningful (Purpose in Life), the possession of quality relations with others (Positive Relations With Others), the capacity to manage effectively one's life and surrounding world (Environmental Mastery), and a sense of self-determination (Autonomy)" (: 720).

Several of these views are also embraced by Ryan and Deci's (2000) *Self-Determination Theory* (reviewed earlier in section 2.4.2.), which highlights the importance of three psychological needs: autonomy, competence and relatedness. The *Flourishing scale* (Diener et al., 2010, 2009, reviewed in section 2.6.2.) also addresses some of these aspects, such as purpose and meaning in life, competence and mastery.

(C) SOCIAL WELLBEING

Arguably, the hedonic and eudaimonic traditional approaches to wellbeing, reviewed above, conceptualise wellbeing as an essentially private phenomenon. Wellbeing of the *private* self is measured as one's individual affect; one's satisfaction with life; and whether *they* live according to *their own* principles. Authors like Corey Keyes have questioned this perspective. Instead, argues Keyes, the self "is both a public process and a private product", and therefore "Inquiry into the nature of well-being should embrace the division of life into public and private tasks" (1998: 121). As such, social wellbeing can be conceptualised as comprising five dimensions:

- Social integration – "the evaluation of the quality of one's relationship to society and community";
- Social acceptance – "the construal of society through the character and qualities of other people as a generalized category";
- Social contribution – "the evaluation of one's social value";
- Social actualization – "the evaluation of the potential and the trajectory of society";
- Social coherence – "the perception of the quality, organization, and operation of the social world, and it includes a concern for knowing about the world". (: 122-23)

The theory was developed in the paradigm of social health, which is a key concern of sociological theory. From this perspective, 'healthier' individuals feel like they are part of society and have something in common with other members of society ('social integration'). They are trusting and believe that others are capable of kindness (social acceptance). They believe they play an important role in society (social contribution). Thinking about society, they believe in its potential to stay on, or change to a positive trajectory (social actualization). While healthier individuals "do not delude themselves that they live in a perfect world", they instead have the desire to know about the world, and to "make sense of life" (p.123) (social coherence).

(D) WELLBEING AS A MULTIDIMENSIONAL CONSTRUCT

The perspectives presented above focus on different meanings of wellbeing, however – as suggested by the WHO definition of the term - these different dimensions may not be mutually exclusive. Wellbeing is increasingly being conceptualised as a **multidimensional construct** because:

> "Well-being is more than just happiness. As well as feeling satisfied and happy, well-being means developing as a person, being fulfilled, and making a contribution to the community" (Shah and Marks, 2004: 2).

National and international initiatives for measuring wellbeing reflect this. As shown before, the UNDP's composite measure of human development (HDI) includes aspect related to health, education and income. Similarly, the *Commission on the Measurement of Economic Performance and Social Progress* – led by economists and social scientists Joseph Stiglitz, Amartya Sen and Jean-Paul Fitoussi (2009) – adopts a multidimensional approach to wellbeing. This covers material living standards as well as non-economic aspects such as health, activity, education, social relationships and sustainability.

A background paper published by the UNDP (Anand, 2016) reviews several approaches used to collect wellbeing measures regularly. Table 2-5 shows that while 'Life satisfaction' appears to be a common theme within the 'subjective' measures used by the European Union, OECD, and the UK's ONS, it is accompanied by different additional indicators. Some are objective and derived from national datasets – such as education or income. Others appear to describe a complex array of potential determinants and mediators, including social, environmental and political factors. However, none addresses the role of the built environment.

Table 2-5. Collection of subjective wellbeing measures at national level on a regular basis. (Anand, 2016: 16)

Country/organization	Subjective measure(s)	Other indicators
Bhutan (Centre for Bhutan Studies)	Psychological wellbeing, social support, mental wellbeing, spirituality, emotional experience	Health, time use and balance, education, cultural diversity and resilience, good governance, community vitality, ecological diversity and resilience, living standards
European Union (29 countries)	Life satisfaction	Material living conditions, productive or main activity, education, leisure and social interactions, economic and physical safety, governance and basic rights, natural and living environment
OECD (34 countries)	Life satisfaction	Income and wealth, jobs and earnings, housing health status, work and life, education and skills, social connections, engagement and governance, environmental quality, personal security
United Nations Children's Fund (UNICEF)	14 questions about domain satisfactions (used with 15-24 year olds)	The Multiple Indicator Cluster Survey covers several aspects of life quality, and has a focus on women, children and health.
United Kingdom (Office of National Statistics)	Life satisfaction Things you do in life are worthwhile Happiness yesterday Anxiousness yesterday	Where we live, personal finance, economy, education and skills, governance, natural environment, our relationships, health, what we do

2.6.2. Measuring wellbeing

Several scales have been developed with the purpose of measuring wellbeing on adult populations in a systematic and meaningful way. The following sections review the operationalisation of hedonic, eudaimonic, social and multidimensional approaches to wellbeing.

(A) HEDONIC DIMENSIONS: AFFECT AND SATISFACTION WITH LIFE

<u>THE POSITIVE AND NEGATIVE AFFECT SCHEDULE (PANAS)</u>

The Positive And Negative Affect Schedule (PANAS) is a self-report questionnaire developed by Watson et al. (1988) in order to quantify two opposite aspects of mood:

- Positive affect (PA), defined as: "the extent to which a person feels enthusiastic, active, and alert"; and
- Negative affect (NA), "a general dimension of subjective distress

and [unpleasant] engagement" (: 1063).

The original PANAS questionnaire includes ten mood descriptors for positive affect, and ten for negative affect; shorter and longer versions of the scale have also been developed, as well as a version tailored for non-adult subjects. Subjects are asked to indicate to what extent they had experienced the twenty moods during the specified time frame ('right now', today, in the past few days, weeks or year, or in general). The selection of the twenty PA and NA descriptors was based on preliminary testing and reliability analyses of a larger sample of 60 mood markers. The descriptors are presented in a varying order and measured on a five-step scale, as shown below in table 2-6.

Table 2-6. PANAS questionnaire content (Watson et al., 1988: 1070)

1 Very slightly or not at all	2 A little	3 Moderately	4 Quite a bit	5 Extremely
	_______Interested*		_______Irritable**	
	_______Distressed**		_______Alert*	
	_______Excited*		_______Ashamed**	
	_______Upset**		_______Inspired*	
	_______Strong*		_______Nervous**	
	_______Guilty**		_______Determined*	
	_______Scared**		_______Attentive*	
	_______Hostile**		_______Jittery**	
	_______Enthusiastic*		_______Active*	
	_______Proud*		_______Afraid**	

*PA descriptors **NA descriptors
Scoring: PA and NA scores are added separately.

The PANAS scale was tested by Watson et al. (1988) on large sample sizes (N ranging from 586 for 'past few weeks' to 1,002 for 'past few days' time instructions), with a smaller sample of 101 providing retest data for all time instructions. The large sample size and the inclusion of test-retest data strengthens the internal reliability of the scale. External reliability tests were also conducted by administering the PANAS scale in conjunction with several pre-existing measures of distress and psychopathology, which revealed statistically significant correlations. However, most of the sample was comprised of undergraduate students enrolled at various psychology courses at a private southwestern university in the US. Data were also collected from small groups of university employees, adults not affiliated with the university, and psychiatric inpatients. The sample characteristics – limited in terms of age, income, social status, education etc. - may raise questions on the validity of the scale for general populations.

THE SATISFACTION WITH LIFE SCALE (SWLS)

The Satisfaction with Life Scale (SWLS) was developed by Diener et al. (1985) to measure life satisfaction "as a cognitive-judgemental process" (: 71). Its five items, copied below (table 2-7), address 'global' life satisfaction *excluding* possibly related constructs such as positive affect or social determinants.

Like the PANAS scale, the SWLS was initially tested on two samples of undergraduate students enrolled in psychology courses (sample 1, n=176 including n=76 retest two months later; sample 2, n=163). To enable external validity analysis, all subjects were also administered a broader "battery of subjective wellbeing measures" (: 72), which revealed moderately strong correlations.

A second study was conducted on 53 elderly subjects (average age = 75). Item-total correlations suggested a good internal consistency of the scale. However, the relatively small sample size and the participant characteristics raise questions of the validity of the SWLS scale for general adult populations.

Table 2-7. SWLS questionnaire content (Diener et al.,1985: 72)

Instructions: Below are five statements with which you may agree or disagree. Using the 1-7 scale below, indicate your agreement with each item by placing the appropriate number on the line preceding that item. Please be open and honest in your responding.						
1 Strongly disagree	2 Disagree	3 Slightly disagree	4 Neither agree nor disagree	5 Slightly agree	6 Agree	7 Strongly agree
______	In most ways my life is close to my ideal.					
______	The conditions of my life are excellent					
______	I am satisfied with my life.					
______	So far I have gotten the important things I want in life.					
______	If I could live my life over, I would change almost nothing.					
Scoring: Add the responses for all five items. Possible range of scores: 5 (low satisfaction) to 35 (high satisfaction).						

(B) EUDAIMONIC DIMENSIONS: THE FLOURISHING SCALE

The Flourishing Scale (FS) (Diener et al., 2009, 2010) is a self-report questionnaire designed to measure “important aspects of human functioning ranging from positive relationships, to feelings of competence, to having meaning and purpose in life” (2010: 146). The eight items of the FS questionnaire are included below in table 2-8.

It is worth noting that although the Flourishing Scale is an overall psychological wellbeing measure, it specifically addresses several aspects of a social nature. Three of its eight items address aspects related to social dimensions of wellbeing, i.e. ‘*My social relationships are supportive and rewarding’;* ‘*I actively contribute to the happiness and well-being of others’; ‘People respect me’.* The remaining items touch on eudaimonic aspects related to living in accordance to one’s own values, feelings of meaning and purpose, competence, and self-realisation.

Table 2-8. Flourishing Scale questionnaire content (Diener et al., 2010: 154-155).

Instructions: Below are eight statements with which you may agree or disagree. Using the 1–7 scale below, indicate your agreement with each item by indicating that response for each statement.

1	2	3	4	5	6	7
Strongly disagree	Disagree	Slightly disagree	Neither agree nor disagree	Slightly agree	Agree	Strongly agree

_______	I lead a purposeful and meaningful life
_______	My social relationships are supportive and rewarding
_______	I am engaged and interested in my daily activities
_______	I actively contribute to the happiness and well-being of others
_______	I am competent and capable in the activities that are important to me
_______	I am a good person and live a good life
_______	I am optimistic about my future
_______	People respect me

Scoring: Add the responses, varying from 1 to 7, for all eight items. The possible range of scores is from 8 (lowest possible) to 56 (highest possible). A high score represents a person with many psychological resources and strengths.

The scale – called ‘Personal Wellbeing’ in previous publications - was tested on a large sample size (n=689) comprised of university students, most of whom were female (n=468). Additional data collected using other relevant self-report wellbeing measures (including PANAS) revealed significant correlations, i.e. high convergence with similar scales. The measure suggested good psychometric properties and internal consistency, however – like PANAS and SWLS – its validity may be limited for people with relatively low educational attainment.

(C) SOCIAL WELLBEING: THE SOCIAL WELLBEING SCALE

Social wellbeing has been conceptualised by Keyes (1998) as being comprised of five dimensions related to integration, acceptance; contribution;

actualization; and coherence.

Two large sample studies were conducted on adult samples to refine and validate the scale (n_1=373; n_2=2,887). Both studies utilised telephone interviews; study 2 used a shorter version of the original 50-item scale and included a supplementary self-administered questionnaire. Additional indicators were measured using established scales in both studies:

- Study 1 participants responded to questions about anomie[14], global psychological wellbeing and community involvement;
- Study 2 measured the following additional indicators: generativity[15], perceived neighbourhood health, perceived constraints, dysphoria[16], self-assessed general health and optimism.

The analysis revealed the scale showed generally high levels of internal consistency. The scales correlated with global indicators of life satisfaction, happiness, and dysphoria in both studies. Correlations with other measures were only found for Study 1 (anomie and community involvement) or for Study 2 (generativity, neighbourhood health, and perceived constraints. Significant effects were found for age and education, suggesting that "social wellness, like all other aspects of health…is graded by processes of social stratification" (: 132).

These findings obtained from a large sample may help validate social wellbeing as a construct. However, the lack of correlation with specific aspects of life suggests that the social, and private domains of life – as measured by

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[14] Anomy, n. - 1. Disregard of law, lawlessness; esp. (in 17th c. theology) disregard of divine law. 2. Also commonly in French form *anomie*. Absence of accepted social standards or values; the state or condition of an individual or society lacking such standards. (Oxford University Press, 2010a)

[15] Generativity, n. - The fact or quality of contributing positively to society through activities such as nurturing, teaching, and creating. (Oxford University Press, 2010c)

[16] Dysphoria, n. - A state or condition marked by feelings of unease or (mental) discomfort (Oxford University Press, 2010b)

different scales – may be related, but do not completely overlap.

(D) WELLBEING AS A MULTIDIMENSIONAL CONSTRUCT: THE WARWICK-EDINBURGH MENTAL WELLBEING SCALE (WEMWBS)

The Warwick-Edinburgh Mental Wellbeing Scale (WEMWBS) is a self-report scale designed for measuring mental wellbeing (Tennant et al., 2007). It is comprised of 14 items covering hedonic, eudaimonic and social aspects of wellbeing (table 2-9 below).

Table 2-9. WEMWBS questionnaire content (Tennant et al., 2007)

Below are some statements about feelings and thoughts. Please tick the box that best describes your experience of each over the last 2 weeks.					
Statements	None of the time	Rarely	Some of the time	Often	All of the time
I've been feeling optimistic about the future					
I've been feeling useful					
I've been feeling relaxed					
I've been feeling interested in other people					
I've had energy to spare					
I've been dealing with problems well					
I've been thinking clearly					
I've been feeling good about myself					
I've been feeling close to other people					
I've been feeling confident					
I've been able to make up my own mind about things					
I've been feeling loved					
I've been interested in new things					
I've been feeling cheerful					

Created by an expert panel from Warwick Medical School and the University of Edinburgh, the scale was developed drawing on a review of literature, focus groups, and was tested on student and representative population samples (n_1=349; n_2=1,749). The scale showed robust psychometric properties including high internal consistency and good content validity. It also showed consistency with scales that cover other dimensions of wellbeing, such as PANAS and SWLS. Its items are all positively worded - a novelty in the field on wellbeing measurement, as shown by the scales reviewed in the previous sections. Since its creation, the scale was used in the Health Survey for England (HSE) in 2010-2013 on nationally representative samples totalling over 26,000 people (Ng Fat et al., 2017).

2.6.3. The role of the workspace

This section has reviewed several measures of wellbeing used in large scale research. These scales explore psychosocial dimensions of wellbeing such as satisfaction, happiness, meaning, or social integration, all of which characterise life, but also *working life* in the context of the workplace environment. Although work and the workspace play important and lengthy parts in most people's lives, none of the authors of these scales have specifically addressed the role played by the workspace – or of the built environment in general. A scoping review of building-related research with a wellbeing focus (Hanc, Mc Andrew and Ucci, 2019) revealed a growing interest in exploring wellbeing in the context of the built environment, but also a lack of clarity surrounding the term and its many conceptual approaches.

As shown by the systematic review of literature presented in section 2.3., workspace research tends to associate wellbeing with physical health – or even defines it as such – and a variety of additional aspects relevant to hedonic, eudaimonic, or social dimensions, such as mood, fatigue, or job satisfaction. This suggests there is no broadly accepted theory of workspace wellbeing.

2.7.The ‘workspace’ / ‘workplace’ productivity and wellbeing knowledge gap

Based on the review of literature, a knowledge gap has been identified in the academic literature dedicated to the study and measurement of workspace (or ‘workplace’) productivity and wellbeing. One approach focuses on the physical dimensions of the workspace environment, while the other, emphasises the psychosocial aspects. This gap is further discussed below.

2.7.1. Productivity and the workspace: Physiological, psychological and social determinants

As shown earlier in section 2.2., productivity can be measured in “**absolute** or **direct** terms by measuring the speed of working and the accuracy of outputs“ (Clements-Croome, 2006: 14-15). In a manufacturing context, measuring productivity simply associated inputs and outputs, with tools such as the stop-watch or the performance recording device used to quantify outputs produced in a specific time frame.

However, for knowledge workers, suggests Drucker (1999), the work process “is not—at least not primarily— a matter of the *quantity* of output. *Quality* is at least as important” (: 84). As knowledge work requires continuous innovation and learning, the responsibility of managing productivity should be imposed on workers themselves: “Knowledge Workers *have* to manage themselves. They have to have *autonomy”* (p.84).

When the option of measuring the outputs of work is not available, **comparative measures** can instead be employed, according to Clements-Croome (2006). These use questionnaires or scales assessing individual *perception* (as revealed in section 2.3.). **Combined measures** can also be used, which assess specific physiological indicators “to see whether variations in the patterns of the brain responses correlate with the responses assessed by questionnaires” (: 15). The role of combined measures, therefore, may be that to obtain *a proxy* for productivity, by measuring physiological indicators of phenomena believed to be closely linked to productivity in knowledge based work, such as concentration:

> “The ability to focus the concentration or alertness for a particular event, such as the work we are undertaking, is an important issue when discussing productivity. For high productivity we need high and sustained levels of concentration centred on the task being carried out.” (Clements-Croome, 2006: 15)

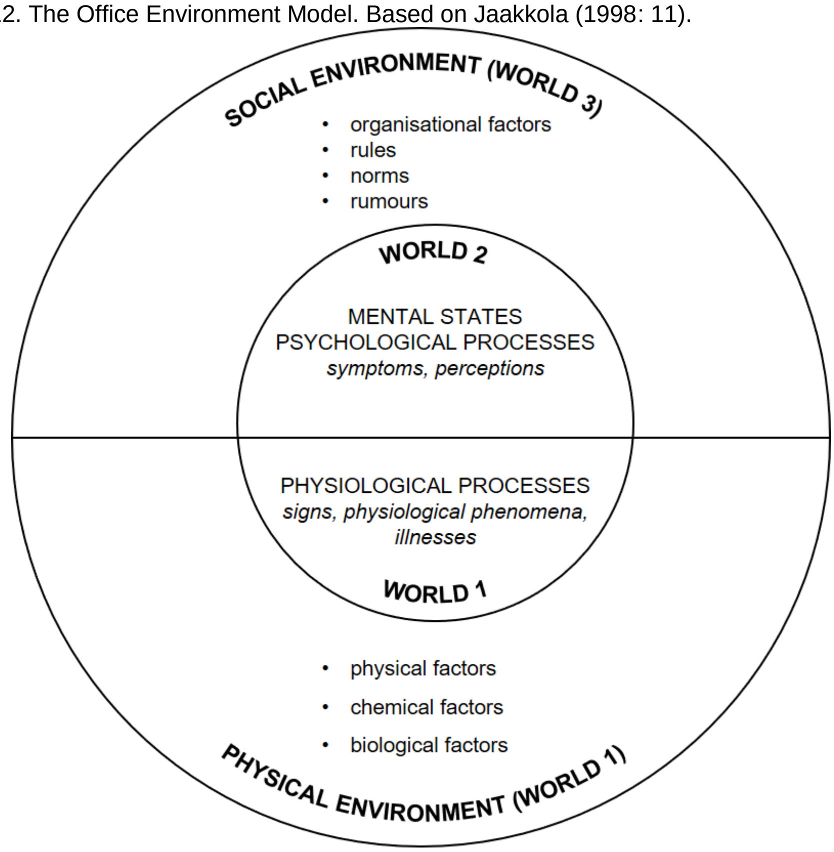
However, the biggest challenge of developing accurate measurements of productivity (and wellbeing) is that **the nature of consciousness is not fully understood**. The neural processes that occur when we think, feel and act in the environments we use, and their effects on our sensations and behaviours are not clear. For example, the concentration believed to be associated with productivity can be disrupted by a breadth of factors with short, medium or long-term effects. These may include “low self-esteem, low morale, an inefficient work organisation, poor social atmosphere or environmental aspects such as excessive heat or noise” (: 15). Workspace productivity can therefore be affected by physiological, psychological or social factors, or a combination of the three.

Similarly, Jaakkola's (1998) model of the office environment, developed in support of his conceptual analysis of the Sick Building Syndrome[17] (SBS),

[17] Sick building syndrome n. a syndrome of uncertain aetiology consisting of non-specific, mild upper respiratory symptoms (stuffy nose, itchy eyes, sore throat), headache and fatigue, experienced by occupants of ‘sick buildings’; (also) the environmental conditions existing in such a building; abbreviated SBS. (Oxford University Press, 1989)

posits the existence of three ‘worlds’ which govern the worker / workspace relationship: Physiological processes (world 1), Mental states (world 2), and Social environment (world 3). (The ‘three worlds’ framework builds on a theory by philosopher Karl Popper). Figure 2-12 schematically describes the relationship between the worker (in the inner circle) and the office environment (“outer circle minus inner circle”: 10). The office environment comprises physical and social factors, which determine the office worker’s physiological and psychological processes. Phenomena of different nature result from the different interactions between these factors. While this diagram was originally intended to explain phenomena related to the SBS, it may also be interpreted as a conceptual description of workspace life, which highlights key actors and responses. Marmot *et al.*, (2006) conducted a cross-sectional study on the associations between the physical environment and SBS symptoms on a sample of 4,052 office-based civil servants. The study revealed no significant relation between the physical work environment and the 10 SBS symptoms investigated. Instead, psychosocial characteristics of work and control over the physical workspace environment were associated with the symptoms.

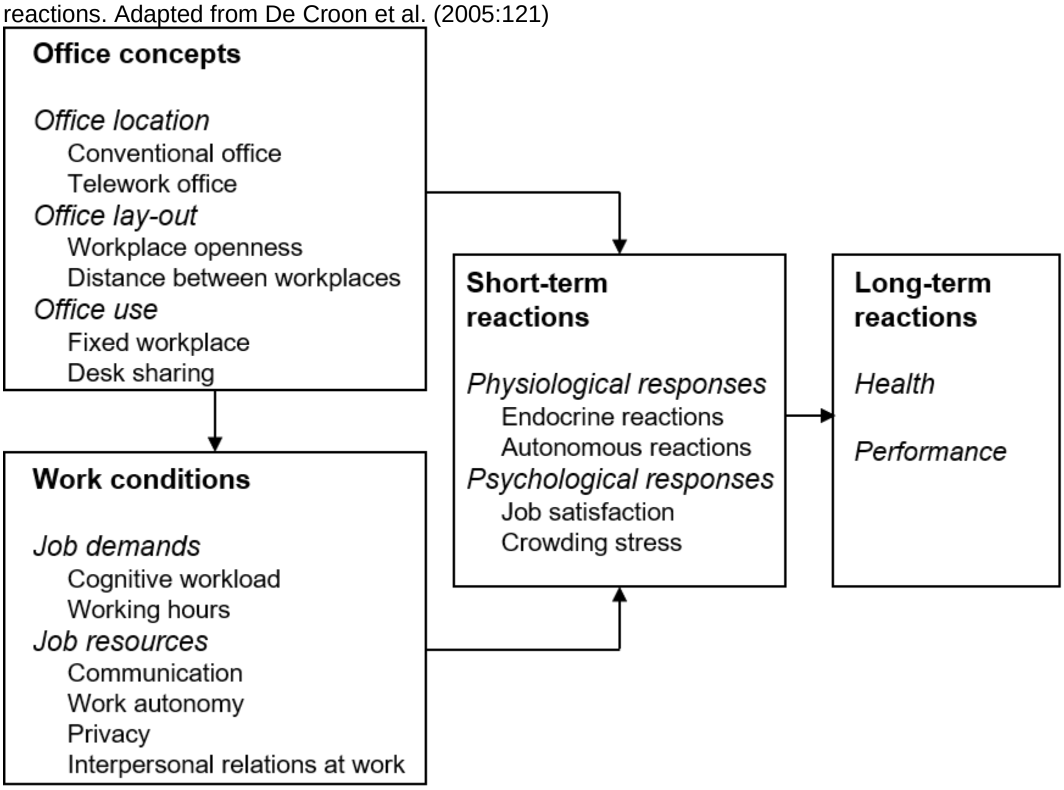
Figure 2-12. The Office Environment Model. Based on Jaakkola (1998: 11).



However, Jaakkola's model – like many theoretical models – may perhaps be too schematic. Firstly, it does not take into account whether different factors might have different reaction times: some physiological processes might occur quickly, while other psychological or social phenomena may develop over time. Secondly, while the literature review supporting the model does provide specific examples of physical, chemical and biological factors within the physical office environment, it does not consider any spatial dimensions of the office environment.

De Croon *et al.* (2005) have adopted a partially similar approach in developing a conceptual model of the hypothesised relationship between office concepts, referring to office location, layout and use, and work conditions, health and performance (figure 2-13). The model was developed to support the authors in conducting a systematic review of the literature on the topic. In contrast to Jaakkola's approach, this model distinguishes between different reaction times, hypothesising that both physiological and psychological responses occur on a short term, while health and performance develop in the long term. The input factors of the model also consider the effect of time, e.g. working hours.

Figure 2-13. Conceptual model that depicts the hypothesized relation from office concepts in terms of office location, office lay-out and office use (via) demands and resources to short- and long-term reactions. Adapted from De Croon et al. (2005:121)

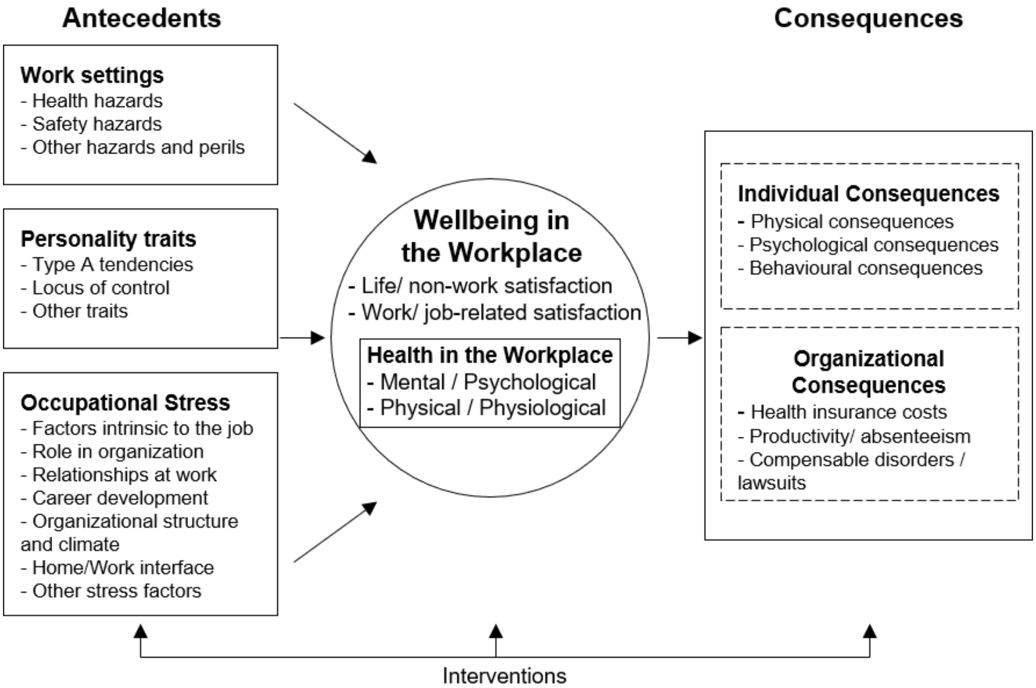


However, whether or not *job satisfaction* is indeed a short-term response and not one developed over a longer timeframe, can be questioned. Secondly, the model provides a clear description of several key elements within the physical office environment – 'office concepts' – and acknowledges the importance of work conditions, which include cognitive, psychological and social aspects.

2.7.2. Wellbeing and the workspace: Physiological, psychological and social determinants

A review of academic literature discussing health and wellbeing in the workplace conducted by Danna and Griffin (1999) synthesised some of the key constructs involved in the relationship (figure 2-14).

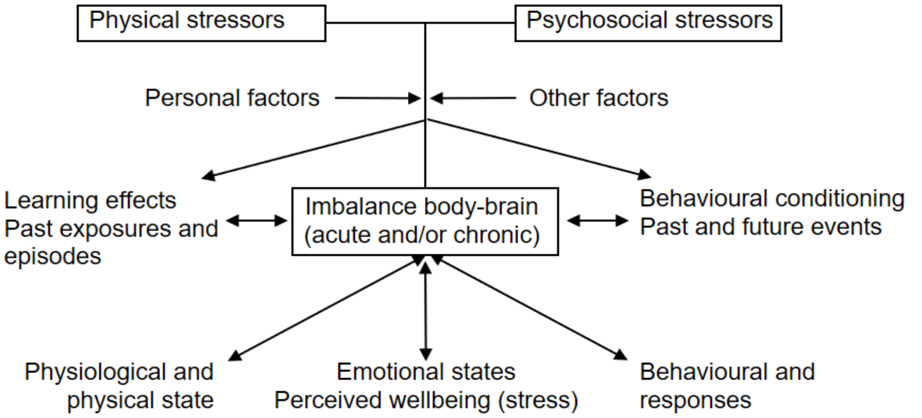
Figure 2-14. A framework for organising and directing future theory, research and practice regarding health and wellbeing in the workplace. (Danna and Griffin, 1999: 360)



Wellbeing is viewed as comprising several dimensions. These include life / personal satisfaction and work / job related satisfaction (both of which may fall under the *hedonic category*, according to the literature review in section 2.5.1 Wellbeing or well-being: Definitions and associated concepts), and health, both mental / psychological, and physical / physiological. The list of wellbeing antecedents comprises psychological factors such as personality traits, and occupational stress, and aspects related to the health and safety of the work settings, but the physical IEQ (internal environmental quality) of the workspace is absent from the list. This echoes a possible knowledge gap between the perspective adopted by social sciences and environmental sciences, as previously noted.

Bluyssen *et al.*, (2011) have conducted a detailed investigation into the various determinants of wellbeing in office environments, as used in the academic literature. As summarised in figure 2-15, their model ('the Human model') posits an imbalance of the human body / brain system by exposure to two types of stressors.

Figure 2-15. Imbalance of the human systems: stressors, factors of influence and responses. Adapted from Bluyssen et al (2011: 2633).



Physical stressors may include building characteristics or parameters, and *Psychosocial* factors may include working conditions (e.g. "job strains such as high demands and low control" (: 2637), working hours or commuting time. However, Psychosocial stressors may also refer to individual problems *beyond the physical domain of the workspace environment*, such as financial worries or marital problems. A full list of components and sub-components suggested by the authors to be included in an IEQ investigation are included in table 2-10 below.

In contrast to WELL, Fitwel or even the Wellness Matters Roadmap, this comprehensive and thorough approach primarily allocates importance to psychosocial determinants of wellbeing. Physical parameters commonly included in IEQ assessments – as revealed in section 2.3 – are only briefly mentioned. Once again, this suggests there is a gap between the wellbeing approaches adopted by social and environmental perspectives. Considering that the physical and psychosocial dimensions of the workspace are related to one another (as shown by Bluyssen and colleagues) research that bridges both perspectives can add a significant contribution to knowledge.

Table 2-10. Suggested components and examples of sub-components of a questionnaire for an IEQ field investigation. Based on Bluyssen et al. (2011: 2637)

Components	Examples of sub-components
Stressors:	
Physical environment	Characteristics of building, systems and rooms: such as windows, view, services (heating, lighting systems), individual control, cleanliness, etc.
Psychosocial environment	Individual such as marital problems, family composition, access to health care and financial stress; working i.e. job strains such as high demands and low control, working hours; commuting such as travel time and queueing.
Physical state	Physical state Perceived health-symptoms (such as SBS symptoms) and perceived comfort – complaints (such as feeling cold, finding the environment smelly, boring or dirty).
Psychological states and traits	Personality to determine one's personal baseline and mood of the moment. For both state and traits, in general the following basic emotions are distinguished: 1. Worry, nervousness, fear and anxiety; 2. Anger, hostility and aggressiveness; 3. Sadness, depression; and 4. Happiness, satisfaction, joy, ecstasy. Additional traits or personality terms that have been used are: negative and positive affect, introversion/ extraversion; coping skills, self-efficacy and locus of control; intelligence and interest.
Other personal factors	Gender, age, (pre-existing) health status (e.g. allergies and asthma), genetics, SES (Socio-Economic Status), diet/nutritional status, education, obesity (BMI index), drugs (ab)use (smoking, coffee, alcohol), marital status, intelligence, environmental sensitivity, crowding (home), family structure, life style, work status, physical activity.
Other factors of influence	Neighbourhood quality, safety (crime and violence), crowding (neighbourhood), time of day, week or month, social support.
Events and exposures	Previous exposure and major life events (how far back depends on the aims and the design of the study: such as smoking history, episodes of depression and anxiety), previous events (causing expectations and worries) and habits (daily events - activity pattern (working hours, sleeping pattern, etc.).

2.8. Summary

The review of literature presented in this chapter revealed several elements central to the study of workplace productivity and wellbeing:

The services sector is the key driver of productivity, employment, and office space demand in advanced and developing economies, including the UK (services account for 83% of employment). The number of knowledge workers – professionals, managers, technical occupations whose jobs involve some or many knowledge tasks – is growing globally and in the UK (60%-70% of the workforce). Global advances in ICT are changing the ways where, when and how work is being performed – many workers now have some degree of choice over space and time of work.

The strong relationship between health, wellbeing, and productivity is being widely acknowledged by initiatives emerging from organisations advocating for best practices in the built environment. However, there are two core models used in the academic literature to explain productivity, and they often exclude each other:

- The ‘workspace’ – environmental parameters such as air quality, temperature, light and lighting, noise, or plants and biophilia determine physiological processes associated with cognitive performance and health.
- The ‘workplace’ – the managerial and social dimensions of the work environment determine psychosocial processes associated with productivity and wellbeing.

Psychological Wellbeing is increasingly being conceptualised as a multidimensional concept, comprised of happiness and satisfaction (*hedonic* dimension), meaning and purpose (*eudaimonic*) and social integration and participation (*social*).

Choice, control, and autonomy are generally believed to lead to beneficial outcomes on wellbeing, social and cognitive development and learning.

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Chapter 3. Methodology

3.1. Research hypothesis and objectives

The review of literature presented in the previous chapter influenced the specific formulation of the research question, particularly the potential effects of *choice / control / autonomy* of the space and time of work on productivity and wellbeing, with workspace quality as a potential mediator.

As outlined in chapter 1, the **research question** is:

Does choice of work space and time affect productivity and wellbeing? What role does the workspace play in this relationship?

The thesis has the following **research objectives**:

Objective 1	To assess the effect of choice of work space and time on productivity, conceptualised as cognitive learning.
Objective 2	To assess the mediating effect of the workspace on the relationship between choice of work space and time and productivity, conceptualised cognitive learning.
Objective 3	To assess the effect of choice of work space and time on wellbeing.
Objective 4	To assess the mediating effect of the workspace on the relationship between choice of work space and time and wellbeing.
Objective 5	To explore workers' perceptions of what elements in the workspace support - and detract from – the ability to work productively.

3.2. Commitment to pragmatism

Scientific inquiry is defined by *paradigms*, or systems of beliefs developed around three fundamental anchors: ontology, epistemology, and methodology (Guba and Lincoln, 1994). Each is concerned with a different question (or group of questions) about the nature and pursuit of knowledge (: 108).

1. Ontology is concerned with the nature of reality and being: *What is the form and nature of reality and, therefore, what is there that can be known about it?*
2. Epistemology addresses the relationship with the process of knowledge acquisition: *What is the nature of the relationship between the knower* [the subject or participant] *or would-be knower* [the researcher or scientist] *and what can be known*?
3. Methodology refers to the processes, methods and tools required by the pursuit of knowledge, i.e. *How can the inquirer (would-be knower) go about finding out whatever he or she believes can be known?*

While paradigms are essentially “human constructions” which in themselves “are not open to proof in any conventional sense” (Guba and Lincoln, 1994: 108), they are paramount for research. A paradigm acts as a conceptual framework that “guides the researcher in philosophical assumptions about the research and in the selection of tools, instruments, participants, and methods used in the study” (Ponterotto, 2005). Several paradigms used in research are schematically presented in table 3-1 below, which synthesises information from several sources (Bryman, 2006; Daly, 2007; Guba and Lincoln, 1994, 2011; Ponterotto, 2005).

This thesis commits to the tradition of **Pragmatism.** This paradigm has arguably become ‘dominant’ in recent decades, and may have emerged as a necessary alternative to the strict stance of Positivism (Morgan, 2007). Pragmatism finds compatibility between the main paradigms that dominated classical research and discovers value in both objective (positivist) and subjective (interpretive) inquiry of the world. In pragmatism, it is the *research question* that determines the methodology, and not some pre-established route to finding truth. Thus, whether or not it is explicitly acknowledged by researchers as a philosophical stance, pragmatism advocates:

> "the pre-eminence of technical decisions about the appropriate use of different methods (either singly or in tandem with other methods regardless of whether they are quantitative or qualitative ones) according to particular circumstance"(Bryman, 2006: 117)

Table 3-1. Brief outline of the Positivism, Constructivism, and Pragmatism paradigms. Based on (Bryman, 2006; Daly, 2007; Guba and Lincoln, 1994, 2011; Ponterotto, 2005).

	Positivism	**Constructivism / Interpretivism**	**Pragmatism**
Ontology What is reality?	The world – both natural and social – exists objectively, is governed by immutable laws and mechanisms and can be understood and explained.	All reality is socially constructed. Multiple and equally valid realities exist and can be understood.	The world exists both objectively and subjectively, as meanings are being developed constantly.
Epistemology What is the relationship with reality? What constitutes valid knowledge?	The investigator and the object investigated are independent entities. Findings are true or false in light of the original hypothesis.	The investigator and the object investigated are interactively linked. Findings are "created" as the investigation proceeds.	Both objective reality and subjective meanings provide valid knowledge in practical applied research.
Methodology How can reality be examined?	Accumulation of evidence from systematic observation and description of phenomena. Quantitative methods – large sample sizes	Interpretation of words and experiences, compare and contrast, finding patterns of meaning. Qualitative methods – detailed observations.	The research question is central in determining the methodology. Mixed methods

Buchanan and Bryman (2007) discuss three trends emerging in organizational research: widening boundaries; multiple paradigms; and methodological inventiveness. Firstly, the boundaries of organisational research have widened and the topics of interest have multiplied considerably. In the 1930s, the Hawthorne experiments researched the impact work schedules, and accidentally discovered a plethora of additional factors that affected productivity and wellbeing. Since then, such ‘factors’ have only multiplied and now include, *but are not limited to*: workplace satisfaction, engagement, empowerment, creativity, fairness, workplace attire, work-life balance. Secondly, the authors show, the field of organisational research is no longer constrained by a specific epistemology. It now displays a variety of perspectives of positivist, interpretive, feminist, and postmodern nature. Thirdly, there is now a good opportunity to translate the great technological advances of the last decades (briefly mentioned in the previous chapters) into methodological inventiveness. Smartphones, digital surveys, wearable biometric devices, or even virtual reality headsets have made it easier to collect, synthesise, analyse, and display useful data of various types.

Consistent with the *pragmatic* approach to research, the methodology was developed according to the **research question** and the practical resources of a doctoral researcher. The following aspects were critical:

- The data collection tools were to be used by a sample of workers who can exercise different degrees of choice over the location and time of their work. This was made possible by the use of applications, hereafter referred to as ‘apps’, deployed on participants’ mobile smartphones, and of digital questionnaires.
- Scheduling aspects were essential, i.e. when and where surveys would be completed in order to provide evidence relevant to the research question. The Ecological Momentary Assessment method (EMA) allowed for the predictor and outcome variables to be measured at the same point in time within participants’ ‘natural environments’ (i.e. their workspaces, wherever they are).
- It was also important to identify how the degree of choice of time and place of work could be measured, and how the key outcomes of productivity and wellbeing were to be established.

The suite of tools was subjected to several stages of pilot testing, then refined, before being applied to the sample population. This chapter reviews the literature of relevance specifically to the selection of the methodology, summarises the lessons learned from the pilots, and finally describes the suite of tools used in the '**Wor**kspace **Q**uality and Choice' package (WorQ).

3.3. Assessing productivity using a cognitive app

The review of literature regarding workspace productivity measurement revealed several key findings that informed the present methodology:

- Traditional productivity metrics based on counting the outputs of industrial or manual production are not applicable to *knowledge work*, that does not typically produce quantifiable outputs (Drucker, 1999); knowledge work is a quality-orientated process which requires continuous innovation and learning;
- Researchers interested in productivity measurement commonly use proxy measures, often involving perceived productivity and/or physiological markers of task or cognitive performance (section 2.3);
- Concentration and mental alertness are often considered as being essential for productivity (Clements-Croome, 2006). This may be particularly relevant for knowledge workers, whose professional requirements involve "high level cognitive activity" (Brinkley et al., 2009: 69);
- Recent developments in cognitive testing using 'serious games' – i.e. games developed for learning purposes – make it possible to conduct cognitive research using smartphone-based cognitive training games on large sample sizes.

For the reasons stated above, the methodology employed by this work has the objective of creating and testing a knowledge productivity proxy metric. This takes the form of **cognitive learning, defined by the author of this dissertation as the improvement of cognitive skills over time**.

The operationalization of cognitive learning in the context of this methodology posed several challenges based on the lack of previous similar examples in the research literature. According to the psychological theories underpinning the hypothesis, *learning* is a process that *develops in time*, under the long-term presence of choice, control or autonomy across different aspects of life. In contrast, cognitive *performance* is conceptualised and measured as a *momentary* assessment of performance in a specific cognitive domain or skill. Cognitive performance is often used as a proxy for productivity in short term, laboratory experiments replicating office workspaces (as shown by the systematic review of literature, section 2.3), but its *longer term evolution* in *natural environments* is underexplored. Yet, sustained productivity may be more relevant to successful organisations than a momentary indicator of achievement. According to Drucker (1999), knowledge work productivity is a process that requires *continuous learning*. **This study operationalises cognitive learning by taking repeated measures of cognitive performance for five days.** While this duration is likely too brief to be considered ‘long term’, it nevertheless proposes a limited, but novel proxy method to assess knowledge work productivity.

3.3.1. Advantages of using smartphone-based games to test cognitive learning

‘Serious games’ (games developed for learning or educational purposes) are increasingly used in research aimed at assessing cognitive performance in clinical, educational or wider settings:

- Knowledge acquisition and cognitive skills acquisition may be more effective when training with serious games, when compared to traditional instruction methods (Wouters et al., 2013);
- Serious games have a wide applicability in research, and can be used to assess diverse cognitive or behavioural outcomes, including Perceptual and cognitive skills, Knowledge acquisition, Affective or Motivational (Connolly et al., 2012)
- Game playing may support self-efficacy or self-determination

> psychological mechanisms associated with feelings of autonomy and competence. They foster engagement, curiosity and motivation to learn.

The potential effects of serious games on learning and behaviour change have been associated with their defining features: they are *interactive* and *goal-directed* activities, conducted within a set of *agreed rules and constraints;* they are often *competitive* as players compete either against each other or against themselves. Finally, they provide immediate *feedback,* thus allowing players to monitor their progress (Wouters et al., 2013). Arguably, serious games are increasingly being accepted in the education or training community as "potentially valuable alternative for conventional ways of training" (Oprins et al., 2015: 328).

The likely appeal of using games for learning purposes may be related to the phenomenon of *Gamification*:

> "Gamification, n.
>
> The application of typical elements of game playing (e.g. point scoring, competition with others, rules of play) to other areas of activity, typically as an online marketing technique to encourage engagement with a product or service." (Oxford University Press, 2018)

Along with the widespread adoption of smartphones and applications ('apps'), recent years have also witnessed the development of smartphone-based learning games. Four commercially available 'brain-training' smartphone apps – as they are described by their developers – were reviewed as part of this dissertation. Their similarities are summarised below, based on information made publicly available by the developers of the apps:

- Two apps were launched in 2007, and two, in 2014. One is UK-based, the other three are US-based.
- In all four cases, the developing teams include several academic advisors specialised in neuroscience, cognitive psychology or cognitive science.
- Each of the apps include 35 to 360 different games which measure and track performance across several cognitive domains including: Concentration or Focus; Problem Solving; Memory; Visual skills; Speed; Language or Writing; Maths.
- Most games are 1 to 3 minutes long. At the end of the game session, scores are revealed indicating their relation to broader rankings or the player's own previous performance, and usually accompanied by a motivating message.
- Some of the apps provide combined training sessions including several games which test different cognitive skills.
- All four apps are available for Android and Apple smartphone devices and have been downloaded 12 to 90 million times.

Some of the games included in the four apps are based on classical tasks from the field of cognitive science. Examples include:

- **The Mental Set and Shift task** explores the 'task switching' executive cognitive function (Jersild, 1927). Subjects are required to complete a set of simple operations performed in a repeating or alternating sequence. Instructions are then given to switch from one type of task to another. The switch between the tasks affects performance. Number of correct tasks performed under a specific time frame is counted.
- **The Stroop Test** (Stroop, 1935) or 'colour and word test' explores the interference or inhibition in reaction time of a task. Subjects are presented with pairs of conflicting stimuli simultaneously, for example "a name of one color printed in the ink of another color — a word stimulus and a color stimulus" (: 647) and ask to signal whether the two match. The reaction time – which is delayed when stimuli are conflicting, i.e. the name of the colour doesn't match the colour – is measured.

The development of *smartphone-based* cognitive training games over the last decade offer several advantages to empirical research:

- Games included in most cognitive training platforms are developed based on knowledge from neuroscience;
- Their scoring mechanisms offer the possibility of obtaining an objective measure of cognitive performance each time the game is played;
- As they are installed onto subjects' own smartphones, they enable the possibility of testing cognitive performance in subjects' natural settings.

For these reasons, the methodology of the WorQ study employed a cognitive training smartphone app to measure learning.

3.3.2. The Peak cognitive training games

After the careful review of several major cognitive training platforms, the Peak brain training app developed by Brainbow Ltd. (2015) was selected and used in this research[18]. The Peak app developers use "a combination of neuroscience, technology and fun to get those little grey cells active and striding purposefully towards their full potential" (Peak, 2018). While colourful and enjoyable, the games are developed with input from scientific advisors, including UCL academic staff from the Institute of Cognitive Neuroscience, or the University of Cambridge, Department of Psychiatry. The commercially available app is intended for personal use, however Peak games have been used in scientific research, e.g. cognitive enhancement in neuropsychiatric disorders and in healthy people (Sahakian et al., 2015). Importantly, Peak offer free access to their app for the purpose of research, including access to a secure digital

[18] A different app was used in pilot stages, as explained in section 3.7.

platform where the research data can be downloaded by the researcher securely, in real time.

Several of the Peak games build on cognitive tasks developed and refined over decades of research, such as the Mental Set and Shift task (Jersild, 1927) or the Stroop Test (Stroop, 1935). The games are short (45 seconds to 2 minutes) and enjoyable, providing instant feedback, and motivational messages after the end of the session.

In addition to these advantages, Peak offered the following opportunities:

- The app includes over 35 games which test several cognitive skills or domains that may be potentially relevant to knowledge work:
    - Language
    - Memory
    - Problem solving
    - Focus
    - Mental agility
    - Emotion
    - Coordination
- The output data downloading from the Peak research platform is comprehensive and easy to use, that can be downloaded as text files; they data files include clear and complete information on the name of the game played, the score obtained, and other statistics relevant for research.
- The Peak research platform offers full anonymity of results. Upon installing the app by signing the consent form virtually, participants are automatically assigned an ID comprised of ten upper case and lowercase letters.

The WorQ research builds on these opportunities by using four of the Peak games to test cognitive performance and learning over three days, as presented in section 3.10.

3.4. Exposure-reaction times in the workspace: The EMA method

This research seeks to understand whether choice of work space and time affects productivity and wellbeing, via the role of workspace quality. The factors or stimuli implicated in this relationship have a diverse nature and different response times. Some may elicit immediate reactions, while others develop over longer periods of time:

> "There are many short-term, medium-term and long-term factors which can contribute towards lowering productivity and these include low self-esteem, low morale, an inefficient work organisation, poor social atmosphere or environmental aspects such as excessive heat or noise." (Clements-Croome, 2006: 15)

Exposure to external stimuli – physical and psychosocial – occurs through the senses (Bluyssen, 2010; Bluyssen et al., 2011). Receptors located in the nervous system collect information through the eyes, ears or skin. Boundary conditions embedded in the endocrine system help protect the body from potential danger or illness (irritation, toxicity) by alerting the limbic system – the part responsible with emotions and evaluations (Bluyssen et al., 2011). For this reason, responses to some physical stimuli should be measured as close as possible to the moment of exposure. Such may be the case of concentration, which is disrupted by temperature, sound or other stimuli *as soon as the respective stimulus has reached levels considered unacceptable by the nervous system.* In parallel, other stimuli might go 'unmarked' by the nervous system at the time of exposure, requiring longer periods for developing a response. Some psychosocial factors – such as the examples suggested by Clements-Croome – may have effect over a longer period of time. In such cases, *measures of the stimuli should be taken repeatedly*.

As the WorQ study is concerned with both momentary and longer term effects, it employs the ecological momentary assessment method (EMA). The EMA method is a subset of the experience sampling method (ESM), "a strategy for gathering information from individuals about their experience of daily life as it occurs" (Hektner, 2010: 446). While ESM focuses on repeated sampling of real time experience or behaviour *wherever* it may occur, the EMA adds the requirement that the sampling occurs **"in subjects' natural environments"** (Shiffman et al., 2008: 1). This is usually achieved by signalling participants to record their thoughts, perceptions, emotions and/or mental states at various points in time during a specific timeframe. Signalling devices can include pagers, pocket calculators, programmed wrist watches (Csikszentmihalyi and Larson, 1987), personal digital assistants (Daniels et al., 2014) or smartphone applications (Engelen et al., 2016).

EMA methodologies have been used in workplace research since the 1970s. Csikszentmihalyi and LeFevre (1989) studied the state of optimal experience (or 'flow') during work and leisure time on a sample of 78 workers from five large companies from Chicago. Participants were signalled to fill in 1 page of their response booklets or 'experience sampling forms' via electronic paging devices ('beepers') that "emitted seven daily signals or «beeps»… sent randomly within 2-hr periods from 7:30 A.M. to 10:30 P.M." (1989: 817). The forms took 1-2 minutes to complete and included items about the activity engaged in at the time of the signal, concentration, motivation (10-point scales), creativity, satisfaction, and relaxation (7-point scales). Similarly, the WorQ study employed digital surveys and a cognitive smartphone application to collect data on variables with different hypothesised response times.

Another advantage of the EMA method compared to other types of data collection is that it measures *perception*, which doesn't typically require specific equipment. Given the scope of the theoretical model – which builds on psychological theories – *perception* over choice and the environment was particularly relevant. Furthermore, the method allows participants' experiences to be recorded *in real time*, in their '*natural environment'* (i.e. the workspace), minimising recall bias and some of the pressures of feeling examined.

Given the expected time and budget constraints of doctoral research, this option was chosen with the aim of maximising the sample size in an effective and inexpensive way. As revealed by the systematic review of literature on workspace productivity and wellbeing measurements (section 2.3), studies conducted in laboratory settings tended to have smaller sample sizes than those who used subjective measures. An additional benefit of conducting an observational study in real life settings, *without the researcher being present,* may minimise the 'Hawthorne effect' as much as possible, i.e. participants' altered behaviour when feeling observed.

3.5. Measuring choice, workspace quality and control

As stated before, the WorQ study adopts a view of the workspace as a physical and psychosocial environment. The variables collected in the study reflect this.

Two independent variables are central to the study: Choice of work space, and Choice of work time. The assumed direction of the relationship is that the higher the degrees of choice, the greater the productivity and wellbeing. While robust work from the social sciences has been conducted on the broad implications of choice, control, and autonomy (as summarised in section 2.4 in chapter 2), however, to the author's knowledge, these two particular aspects of choice have not yet been widely explored.

This presented both an opportunity to contribute to knowledge by exploring this phenomenon, and a challenge from an operational point of view. Several questions were central to the methodology: *how* should perception of choice be measured; *how* often should it be measured (as a general measure, or using momentary assessments; how often can the degree of choice change in the workspace settings?); should choice of work space and time be measured separately, or should a compound variable be created; are there any other associated variables.

At the same time, as the literature review has shown, robust evidence exists on the implications of workspace IEQ, and control over the attributes of the environment, on outcomes including productivity, satisfaction, and wellbeing. Workspace IEQ and Control of attributes variables are considered as mediators of the hypothesised relationship.

The WorQ study builds on knowledge from the environmental sciences to create a framework for measuring choice of work space and time. The two key predictors – choice of work space and choice of work time – and mediators – workspace IEQ and control of attributes - are measured using techniques used in robust post occupancy evaluation (POE) studies, such as the BUS or CBE Berkley, reviewed in the following section:

- Data collection uses questionnaires, appropriate tools when measuring perception;
- Seven – step scales are used.

As per the study's EMA design, the four variables are measured daily, at the same time (around lunch time), for five days. The full content of the questionnaire is included in section 3.8.

3.6. Wellbeing as a multidimensional construct: SWEMWBS

Sections 2.5.1and 2.5.2 reviewed three key approaches to conceptualising and measuring wellbeing: Hedonic, Eudaimonic, and Social. However, more recently, the gap between these approaches is beginning to narrow. Wellbeing is starting to be defined as a holistic phenomenon, that includes happiness, satisfaction, but also personal growth and development, and making a social contribution (Shah and Marks, 2004).

This work considers wellbeing as a **multidimensional construct** comprising hedonic, eudaimonic and social wellbeing aspects related to mental health. While the role of physiological determinants to health and wellbeing is acknowledged (as shown by the literature review), this research deliberately focuses on the mental processes conducive to wellbeing and productivity.

For this reason, the Warwick-Edinburgh Mental Wellbeing Scale (WEMWBS) may be an appropriate option (Tennant et al., 2007). Developed by a collaboration between Warwick Medical School and the University of Edinburgh, the scale has shown robust psychometric properties upon its validation on population and student samples. WEMWBS may be “a good way to find out about feelings and thoughts in different environmental settings which can act as a background indicator to see if the environment is a contributory factor to negative or positive well-being” (Clements-Croome, 2018: 12)

A shorter 7-item version of the scale was developed in 2009 by the authors by selecting the seven of the original 14 items that displayed the best fit with a Rasch model of conjoint measurement. This was called Short version of the Warwick-Edinburgh Mental Wellbeing Scale (SWEMWBS) (Stewart-Brown et al., 2009). Statistical analysis on the HSE samples found robust psychometric properties of the short version, whose performance was similar to the longer version (Ng Fat et al., 2017):

> “The items in SWEMWBS present a picture of mental wellbeing in which psychological functioning dominates subjective feeling

> states, but the superior scaling properties and reduced participant burden have made it the instrument of choice in some studies" (: 1130).

The WorQ study used the short version of the Warwick-Edinburgh scale. Given the nature of the methodology – which required participants to spend approximately 4 minutes per day completing the cognitive tests, and several more, to complete a questionnaire – the advantages of using a shorter but equally meaningful version of the scale were important. The original time frame instructions of the scale – which asks subjects about their feelings 'over the last two weeks' – have been altered to 'last week' to obtain a closer overlap with the study week.

3.7. Measuring workspace indoor environmental quality (IEQ)

This section reviews and compares two of the most comprehensive and widely used tools for measuring IEQ in the UK and the US:

- The Building Use Studies (BUS) occupant survey method (Building Use Studies, 2018);
- The Occupant IEQ Survey method developed by Center for the Built Environment (CBE), an industry / academic research collaboration based in the University of California, Berkeley.

While other, and perhaps more specific, methods exist for measuring occupant satisfaction with the built environment (as shown by the systematic review of literature, section 2.3), the BUS and CBE surveys were deemed most appropriate for the scope of this research. Both adopt comprehensive and robust approaches, based on decades of continued development and applied to large sample study of buildings, typically POE. The current BUS survey "evolved originally from the 1985 BUS Office Environment Survey questionnaire" (Building Use Studies, 2011: 4), while the CBE has been used and continuously refined since 1997. Neither of the two surveys are available in the public domain, although comprehensive information on the background, methods and related publications is available on the BUS and CBE websites. The review is based on copies of the surveys provided to the author of the thesis by the relevant contacts in 2016.

Several similarities can be observed:

1. The structure of the survey and order of collecting the variables is similar, with the Background information collected first, followed by questions about the workspace. Both the BUS and CBE surveys collect information on age (using age grouping), gender, occupation and time spent working in the building and work area.
2. Both surveys collect quantitative and qualitative information on seven environmental parameters of the workspace. These are: Thermal comfort, Air quality, Noise, Lighting, Layout, Furnishings, Cleanliness. The degree of **personal control** over these attributes is also measured by both surveys.
3. Most quantitative rating questions in the two surveys use **seven step scales**, and usually express ‘satisfaction’ with the parameter under investigation. In the BUS survey, the scales range from ‘Unsatisfactory’ to ‘Satisfactory’, while in the CBE survey, they range from ‘Very satisfied’ to ‘Very dissatisfied’. No intermediate values (such as ‘neutral’ or ‘neither / nor’) are provided in either case.
4. Seasonal differences are measured by BUS (Temperature and Air quality in winter / summer), and CBE (Thermal comfort in ‘warm/hot weather’, and ‘cool/cold weather’, respectively).

Perhaps due to the different formats of the surveys – BUS uses a three-page, paper-based format, while CBE is web-based – some differences exist in the way that variables are operationalised.

1. While both surveys address the issue of ‘comfort’, this is operationalised differently:
    - In the BUS survey, the Comfort section regards winter

and summer values of satisfaction with: temperature; air quality (both operationalised using several aspects); and overall comfort in the building and in the work area.

- The CBE measures comfort with: office furnishings; temperature (warm, and cold weather); visual comfort of lighting. At every step, information about the sources of discomfort is gathered.

2. The perceived impact of the IEQ on productivity is measured at a different level of detail:
   - BUS uses one quantitative question ('Productivity at work' on a nine-step scale from -40% or less to +40% or more), providing additional space for comments.
   - CBE includes questions about productivity in relation to every major variable measured in the survey: office layout; office furnishings; thermal comfort; air quality; lighting quality; acoustic quality; cleanliness and maintenance.
3. The identification of workspace location within the building is perhaps more accurate in the CBE survey, which allocates an entire section to it, i.e. floor, area of the building, direction of the closest window, external wall or windows within 15 feet. The BUS survey collects information two aspects: the size of the workgroup (5 options possible), and proximity to window (yes or no).
4. Privacy is only measured by the CBE survey, which measures visual privacy and acoustic privacy separately.
5. Perceived health, Effect on behaviour, Occupation density and Response to building problems are only measured by BUS.

Table 3-1 presents a summary of the comparison.

Table 3-1. Occupant IEQ surveys: Comparison between BUS and CBE (Building Use Studies, 2011; UC Regents, 2018)*.

	Building Use Studies (BUS) 2015 version	**Center for the Built Environment (CBE)** Version revised in March 2009
Background information	Age; Sex; Name; Department; Building is normal base; Workgroup size; Window seat; Time in the building; Time at current work area; Days spent in the building weekly; Hours per working day in the building; Hours per working day at the work area; Hours per working day working at computer screen.	Time in the building; Time at current work area; Hours per working day at the work area; Occupation; Age; Gender.
Descriptive data - Comments	Building design; Needs; Meeting rooms; Storage; Work requirements: things that hinder effective working / work well; Desk or work area; Noise; Lighting conditions; Comfort overall; Productivity at work; Health; Controls usability; Effect on behaviour; Occupation density; Response to problems.	Office layout; Temperature; Air quality; Lighting; Acoustic quality; Cleanliness and Maintenance; Energy use; Building design and operation.
Data collection	Paper (recommended), web-based possible. Data are typed into pre-formatted Excel data files.	Web-based. Survey results are viewed via an advanced interactive reporting tool.
Database benchmarking:	Yes	Yes
• Buildings surveyed	• The most recent 50 buildings studied (benchmarks updated annually)	• 1,000
• Occupants surveyed	• Unknown	• 100,000

* The original structure, terms used and order in which variables are collected are maintained.

Table 3-1. Occupant IEQ surveys: Comparison between BUS and CBE (Building Use Studies, 2011; UC Regents, 2018) (continued).

	Building Use Studies (BUS) 2015 version	**Center for the Built Environment (CBE)** Version revised in March 2009
Core sections	**The building overall** Building design; Needs; Space; Image of building to visitors; Safety; Cleaning; Meeting facilities; Storage. **Occupation and Work requirements** **Desk or work area** Furniture; Space at desk. **Comfort – winter and summer** Temperature (3 aspects); Air (4 aspects); Overall conditions **Noise** **Lighting** **Comfort overall** **Productivity at work** **Health** **Personal control** Heating; Cooling; Ventilation; Lighting; Noise; Controls usability. **Effect on behaviour** **Occupation density** **Response to problems** Speed of response; Effectiveness of response	**Personal Workspace Location**: Floor, Area of the building, Direction of closest windows, external wall within 15 feet, window within 15 feet. **Personal Workspace Description**: **Office layout:** Space for work and storage; Visual privacy; Interaction with co-workers; Office layout enhances / interferes with ability to get job done. **Office furnishings:** Comfort of office furnishings; Ability to adjust furniture; Colours and textures of flooring, furniture and finishes; Office furnishings enhances / interferes with ability to get job done. **Thermal comfort:** Thermal controls; Temperature; thermal comfort enhances / interferes with ability to get job done; Temperature in warm/hot weather and cool/cold weather; Time of day when discomfort occurs; Sources of discomfort. **Air Quality:** Overall air quality; Air quality enhances / interferes with ability to get job done; Air is stuffy/stale; Air is not clean; Air smells bad; Sources of air odour. **Lighting:** Lighting controls; Amount of light; Visual comfort of lighting; Lighting quality enhances / interferes with ability to get job done; Sources of lighting dissatisfaction. **Acoustic Quality:** Noise level; Sound privacy; Acoustic quality enhances / interferes with ability to get job done; Sources of dissatisfaction with acoustics. **Cleanliness and Maintenance:** General cleanliness of the building; Cleaning service; General maintenance of the building; Cleanliness and maintenance enhance / interfere with ability to get job done. Cleaning service – frequency of dissatisfaction; Sources of dissatisfaction with cleaning service. **Building Features:** Energy use; other specific building features can be introduced in the survey, e.g. thermostats, light switches, exterior shades, security system.

* The original structure, terms used and order in which variables are collected are maintained.

3.8. Qualitative data: The supportive / disruptive workspace

Research decisions taken to support a particular hypothesis may skew the design towards finding effects exclusively related to the parameters being investigated. By doing so, opportunities are being missed to reveal other potentially relevant underlying phenomena within the workspace, and the deepening of the knowledge gap between environmental and social sciences approaches to the workspace. Surveying participants' views may, therefore, be an important tool for obtaining nuances that might otherwise go unnoticed.

To complement the qualitative data collected in the WorQ study, qualitative data were also collected on the perceived effects of the workspace on productivity. Two separate questions were asked about how the workspace supported, and disrupted, respectively, participants' ability to work productively.

Data were collected across five days and the content was explored using thematic analysis.

3.9. Pilot testing and revisions

Pre-pilot and pilot studies were conducted in order to test the innovative aspects of the research methodology – i.e. smartphone based cognitive testing. These are described in table 3-2 below.

Table 3-3. Pre-pilot and pilot studies conducted to refine the research methodology.

Study	Data collection schedule	Sample / dropout	Lessons learned
Pre-pilot 1 (2015)	Cognitive testing via GBE*: 1 game (7 min.) 2x day x 10 working days Workspace IEQ and work types: digital questionnaire 2x day x 10 working days Demographics and general Choice of work space and time: collected once Wellbeing: WEMWBS (14 items) collected in day 10	9 (45%) Researcher's contacts undertaking paid work	Too many requirements – high dropout rate → Reduce data collection schedule: → 1 working week instead of 2; → 1 cognitive testing session x day instead of 2 → Refine questionnaire content and wording

Study	Data collection schedule	Sample / dropout	Lessons learned
Pre-pilot 2 (2015)**	Cognitive testing via GBE: 1 game (7 min.) 1x day x 5 working days Workspace IEQ: digital questionnaire 1x day x 5 working days Demographics, general Choice of work space and time: collected once in separate digital questionnaire Wellbeing: WEMWBS (14 items) and Feedback: day 5	22 (54%) Research sponsors' employees	High dropout rate: of the 48 employees who answered the separate demographic section, only 22 completed the study. → Integrate questionnaires → Cognitive game and questionnaire 'too long' – use short version of WEMWBS (7 items) → 1 to 5 Likert scale does not sufficiently capture IEQ nuances – use 1 to 7 instead
Pilot (2016)	Cognitive testing via Peak app: 4 games (<1 min each) 1 x day x 5 working days Links to IEQ questionnaire included in the app – 1 x day x 5 working days Wellbeing: Short WEMWBS (7 items): day 5	9 (70%) UCL Bartlett PhD students and research staff	High % of incomplete data after day 3 (data collection conducted in week preceding winter holiday): → avoid data collection in weeks before / after bank holidays → collect wellbeing in day 3 instead of day 5; → take first 3 cognitive test results into account for main analysis (max. sample size) Questionnaire links didn't always work: → keep cognitive testing and questionnaire separate Cognitive games perceived as 'fun' - some participants played them more than 1 x day → keep the games → improve clarity of participant instructions → define solid inclusion / exclusion criteria

* The Great Brain Experiment (GBE) smartphone application developed by researchers from UCL and the Wellcome Trust to test cognitive performance using games. The cognitive game chosen for the pre-pilot studies was 'How much can I remember?' which tested working memory (McNab et al., 2015).
**The study is briefly presented in a conference paper (Hanc, 2016) included in Appendix A (page 319).

Each of the intermediate stages revealed a requirement to reduce the demands of the testing protocol to reduce dropout rates, without affecting the quality and reliability of the data being collected and their ability to answer the research question:

- Data collection schedule was reduced from twice a day for two weeks (in the first pre-pilot) to once daily for five working days;
- The use of four shorter cognitive tests (45 seconds – 1 minute each), instead of a single, 6 minute long one;
- The use of the short version of the WEMWBS scale (7 items);

(A) METHODS NOT BEING USED

Several additional research methods – both quantitative and qualitative - would have enriched this work, however an assessment of their feasibility revealed they would incur additional costs and/ or cause significant delays. A *pragmatic* decision was made to exclude them from the present methodology while suggesting them as possible directions for future work. The reasons why these methods were excluded are primarily related to one defining feature of this research: **this study is not focused on one or several specific companies, but on UK knowledge workers, wherever (and whenever) they may work**.

The methods considered and excluded from the methodology were:

- **Interviews and focus groups**, which require considerable time and resources for planning, organisation, recruitment and travel (on the researchers' side), and obtaining necessary approvals, internal recruitment, and liaising with the researcher (on the companies' side);
- **Physical measurements using sensors or data loggers**, which require additional financial resources and, most of all, logistical problem solving. Approvals would need to be obtained from companies willing to participate, and the researchers' access must be granted.
- **Direct observations of workers** would not have been applicable – some participants work from home or other locations.
- **Wearable biometric devices,** which would have incurred significant costs, and would likely raise data security concerns from participants.

3.10.Outline of the WorQ study

The resulting methodology package was termed 'WorQ', short for the '**Wor**kspace Choice and **Q**uality Study', which explore the effects of choice of work space and time on productivity and wellbeing and the mediating role of workspace quality. The study is covered by the UCL Data Protection Registration, reference No Z6364106/2016/11/67 social research (a full description of Research ethics and data protection approach is included in Appendix C). The WorQ study adopts an ecological momentary assessment method (EMA) described below:

(A) CONSENT

Informed consent was obtained from participants in the week prior to the testing period. They received digital copies of the study instructions and installed an application, later referred to as 'the app', on their smartphones free of charge with login details provided by the researcher.

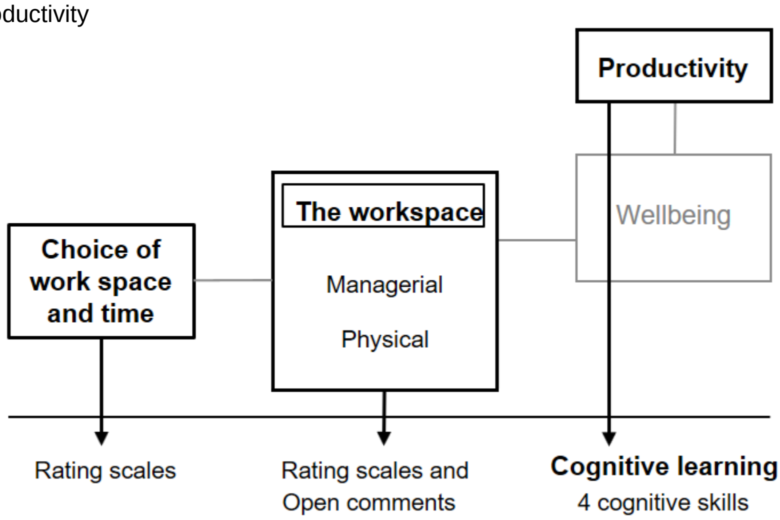
(B) DATA COLLECTION

During the following five working days ('the study week'), participants completed a digital questionnaire, then completed four cognitive tasks on the app. Both actions were completed once every day, around midday. The questionnaire measured different variables – some daily, others just once; quantitative and qualitative techniques were used, as below.

DAILY MEASURES (5 DAYS):

- **Choice of work space and time** was measured every day using rating scales;
- **Workspace quality** was measured every day using rating scales and open questions.
- The **cognitive performance** outcome – considered as a proxy for productivity - was measured every day via the scores obtained at the four tasks included in the app.

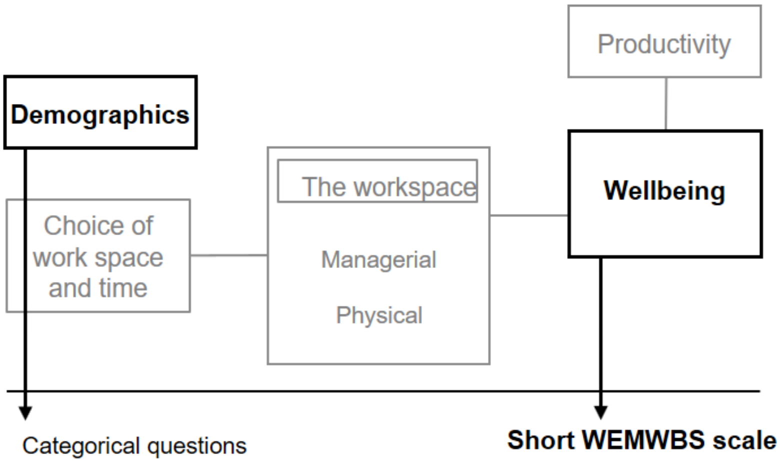
Figure 3-1. Operationalisation of theoretical model (1) Variables measured daily: Choice, Workspace quality and Productivity



SINGLE MEASURES:

- **Demographic information** was collected once (day 1).
- **The Wellbeing** outcome was measured once (day 3).

Figure 3-2. Operationalisation of theoretical model (2) Variables measured once: Demographic information and Wellbeing



(C) SCHEDULE

The pilot and pre-pilot studies (table 3-1) showed a significant participant dropout point in day 3, although some participants did complete the study for five days as instructed. To make the most of the available data, participants are instructed to complete the study for five working days, although the outcome measure for both cognitive performance and wellbeing is day 3.

3.11. WorQ questionnaire content

The full content of the questionnaire used in the WorQ study is presented below. Table 3-3 summarises the questions asked daily, which refer to choice of work space and time, workspace premises and type used in the last hour, IEQ and control over this workspace. A specific question only applies to working from home, and was not shown to participants who stated they worked in their office buildings or elsewhere.

Tables 3-4 and 3-5 include the Demographic and Wellbeing sections, respectively, which were completed once in day 3. In addition to this, nine specific workspace IEQ items were measured in day 3, as summarised in table 3-6. These referred to the workspace used in the last hour and participant satisfaction with the quality of the following features:

- Temperature;
- Air Quality;
- Natural light;
- Artificial light;
- Noise;
- Usability of furniture;
- WiFi, IT and work technologies;
- Design and aesthetics;
- Privacy.

Table 3-4. Content of the WorQ study daily questionnaire (asked daily for five days, midday)

Variable	Question	Response options
Choice of work space	Thinking about your workday so far, were you able to choose WHERE you worked? Please choose an option from 1 (No choice) to 7 (Full choice)	1 (No choice) to 7 (Full choice)
Choice of work time	Thinking about your workday so far, were you able to choose WHEN you worked? Please choose an option from 1 (No choice) to 7 (Full choice)	1 (No choice) to 7 (Full choice)
Workspace location	Where did you work in the LAST HOUR?	In my office building At home* Other (please specify)
Workspace type	(A) Which space in the office building?	Enclosed office - Just used by me Enclosed office - Shared with 1 to 7 colleagues Open plan office - 8 or more people - Desk / workspace always assigned to me Open plan office - 8 or more people - Desk / workspace NOT assigned to me Small, enclosed, quiet space / office phone booth Meeting space Cafeteria, lounge area or kitchen Other (please specify)
	(B) Which space in your home?	In a designated, enclosed workspace / home office Desk or table in the Living / Dining / Kitchen area Desk or table in my Bedroom
*People at home	(C) Was anyone else at home when you were working there?	Yes - a friend or partner Yes - a child or dependent Yes - several flatmates / family members / friends No - I was home alone
(Q) Productivity supporters	Thinking about the workspace you used in the LAST HOUR... How did this space SUPPORT your ability to work productively?	
(Q) Productivity disruptors	Thinking about the workspace you used in the LAST HOUR... Did any attributes of this space DISRUPT your ability to work productively?	
Workspace IEQ	Overall, how SATISFIED were you with the attributes of this space in the last hour? Please choose an option from 1 (Very dissatisfied) to 7 (Very satisfied)	1 (Very dissatisfied) to 7 (Very satisfied)
Control of workspace attributes	How much CONTROL did you have over the attributes of this space in the last hour? Please choose an option from 1 (No control) to 7 (Full control).	1 (No control) to 7 (Full control).

* This question was only asked to participants who stated they worked from home

Table 3-5. Content of the WorQ study Demographic section (questions asked once in day 1)

Variable	Question	Response options
Age	What is your age?	20 – 29 30 – 39 40 – 49 50 – 59 60 – 69 Other
Gender	Please state your gender	Male Female Other
Education	What is the highest degree or level of education you have completed?	High school Apprenticeship or Diploma Bachelors Degree Masters Degree Other
Employment	What is your current state of employment?	Full-time Part-time Self-employed Other
Industry	Which industry best describes your professional activity?	Wholesale and retail trade Financial and insurance activities Real estate activities Professional, scientific and technical activities Administrative & support service activities Education Other
Occupation	How would you describe the work that you do?	Manager / Director / Senior official Professional Associate professional / Technical Administrative / Secretarial occupations Skilled trades Caring / Leisure / other Service occupations Sales / Customer service occupations Process / plant / machine Operative Elementary occupation Other
Job control	In general, how much control do you have in organising and performing your work?	1 (No control) to 7 (Full control)
Language	Is English your first language?	Yes / No

Table 3-6. Content of the WorQ study Wellbeing section: SWEMWBS (asked once in day 3)

Below are some statements about feelings and thoughts.
Please tick the box that best describes your experience of each over the last week*

Statements	None of the time	Rarely	Some of the time	Often	All of the time
I've been feeling optimistic about the future					
I've been feeling useful					
I've been feeling relaxed					
I've been dealing with problems well					
I've been thinking clearly					
I've been feeling close to other people					
I've been able to make up my own mind about things					

* The original time instructions of the scale – 'over the last two weeks' – have been altered to 'last week' to obtain a closer relation to the study week.

Table 3-7. Content of the WorQ study detailed IEQ section (asked once in day 3)

Variable	Question	Response options
	Thinking about the workspace you used in the LAST HOUR, how satisfied were you with its features? Please choose an option from 1 (Very dissatisfied) to 7 (Very satisfied)	1 (Very dissatisfied) to 7 (Very satisfied)
Temperature		
Air Quality		
Natural light		
Artificial light		
Noise		
Usability of furniture		
WiFi, IT and work technologies		
Design and aesthetics		
Privacy		

3.12. Measuring cognitive learning

3.12.1. Assessing performance on different cognitive areas

As stated before, this work uses cognitive learning as a proxy for measuring knowledge work productivity. As such, the metric intends to be comparable (as much as possible) with the expected demands of knowledge work. According to the literature, knowledge work requires “high level cognitive activity” (Brinkley et al., 2009: 69) *across different cognitive domains*. As such, a decision was made **to test performance on four different cognitive games, which tested different cognitive skills and tapped into different cognitive domains.**

This approach reflects findings from the research literature. As shown in chapter 2, section 2.3., empirical productivity experiments consider performance on **several cognitive domains** as proxies for productivity. Lan & Lian (2009) used as many as thirteen neurobehavioural tests to explore the impact of temperature on productivity. These were: *overlapping; conditional reasoning; spatial image; memory span; picture recognition; visual choice, letter search; number calculation; symbol–digit modalities test*; *event sequence; reading comprehension; graphic abstracting* and *hand–eye coordination*. In a systematic review of literature on self-administered mobile cognitive assessments, Moore, Swendsen and Depp (2017) revealed that a combination of cognitive skills are often tested in research. Examples include *reaction time and working memory*; *semantic memory and episodic memory*; *processing speed and working memory; attention and working memory.*

Four different Peak games were used in the WorQ study, as shown in table 3-8 and figure 3-3. Using four tests that tap into different cognitive skills is also motivated by an intention to replicate (as much as possible) the cognitive demands of knowledge work. These might require a combination of specific skills (e.g. language or visual attention), as well as more general abilities to sustain attention or switch between different tasks, which may implicate working memory.

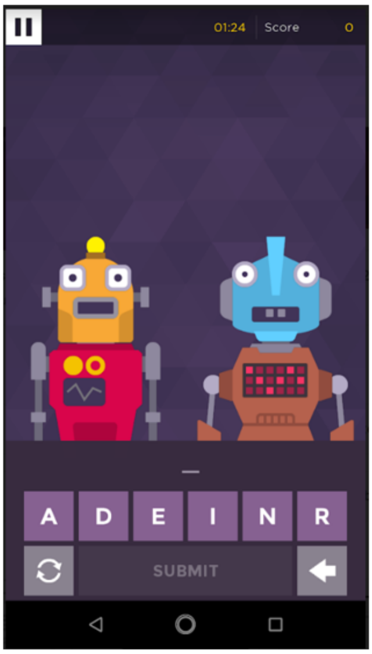
Table 3-8. Peak games used in the WorQ study. Compiled based on text and images from the Peak cognitive training application (Brainbow Ltd, 2015).

Full and shortened name of game	Cognitive domain	Specific skills	Instructions	Time
Babble Bots (BAB)	Language	Word fluency, Working memory	Create words of 3 letters or more by tapping the letters and pressing “Submit”. Use Delete button if you make a mistake. Create words quickly to activate the score multiplier!	1:30
True Color* (TCR)	Mental agility	Task Shifting Response Control	A word and a colour will appear on the cards. Determine if the word at the top matches the colour at the bottom. Ignore the meaning of the word at the bottom and focus just on its colour.	0:45
Tunnel Trance** (TUN)	Focus	Working Memory, Sustained Attention, Visual Recognition	Compare the shape on screen with the one displayed 2-back. Memorize the first shape. Memorize the second shape. Does the current shape match the one from 2 steps before that?	0:45
Unique (UNI)	Focus	Visual Attention, Visual Recognition	Find the odd one out and tap on it.	1:10

* Game builds on the Stroop Colour and Word Test (Stroop, J.R., 1935).
** Game builds on the Mental Set and Shift task (Jersild, 1927)

Figure 3-3. Instructions of the PEAK games used in the WorQ study. Compiled based on text and images from the Peak cognitive training application (Brainbow Ltd, 2015).

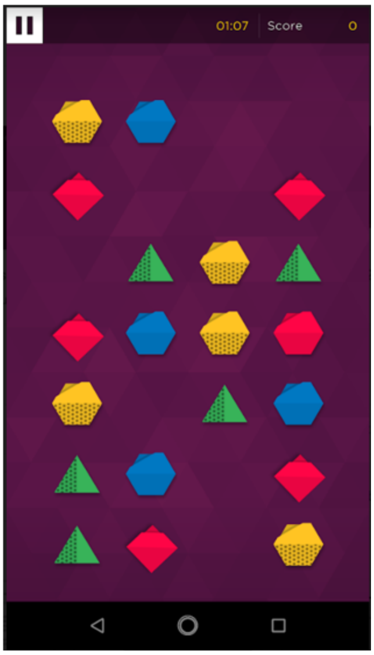
Babble Bots (BAB)
Create words of 3 letters or more by tapping the letters and pressing "Submit". Use Delete button if you make a mistake. Create words quickly to activate the score multiplier!



True Color (TCR)
A word and a colour will appear on the cards. Determine if the word at the top matches the colour at the bottom. Ignore the meaning of the word at the bottom and focus just on its colour.

Tunnel Trance (TUN)
Compare the shape on screen with the one displayed 2-back. Memorize the first shape. Memorize the second shape. Does the current shape match the one from 2 steps before that?

Unique (UNI)
Find the odd one out and tap on it.



3.12.2. Duration and data collection schedule

As shown above, the study uses several measures of cognitive performance collected at different points in time. Examples from the literature are considerably diverse with regards to the timing of measuring cognitive performance. A systematic review of academic literature on self-administered mobile cognitive assessments in clinical research (Moore et al., 2017) found that “studies sampled participants between 1 and 6 times per day for 1 to 14 days” (: 1).

The five-day data collection schedule used in this study was chosen to reflect the settings of a working week as much as possible. **However, as explained before, the main body of analysis concerns the first three days, after which significant drop out rates were predicted to appear based on the pilot studies.**

3.12.3. Assessing learning

Due to the scarcity of clear examples on how to assess learning using smartphone-based cognitive training games in time, several ways of assessing learning were considered. Two distinct approaches are possible:

a. Using the absolute scores to observe the between-subjects score ranges and variability;
b. Creating a standardised learning metric to observe the within-subject rate of progress during the testing period.

For a number of reasons, the second option is considered the most appropriate. Should the absolute scores be used, the variability would perhaps reflect effects due to chance or individual differences between participants’ pre-existing skills or experience. Some participants may perhaps frequently exercise one or more of the cognitive domains being tested while others may not, therefore comparing their scores may not be necessarily meaningful. Instead, creating a standardised metric that assesses *individual* learning achieved over the testing period would allow participants’ scores to be compared against their own first scores.

This learning metric aims to synthesise participants' entire rate of progress on the cognitive tests during the testing period, or their 'learning curve'. However, initial explorations of the method during pilot phases showed that:

- Practice – i.e. the repetition of testing - affects performance on the tests: scores obtained in the latter testing days are usually higher than those obtained in the former days;
- The shape of the learning curves may vary: scores may increase continuously for some participants, but may also decrease, and/or recover and increase again.

There is broad agreement that repetition, practice and time affect learning. According to a widely cited theoretical framework, expert level performance is believed to be the result of prolonged, conscious efforts to improve one's skills, i.e. deliberate practice (Ericsson et al., 1993). Yet, to the author's knowledge, no previous examples show how to quantify the exact contribution that *practice alone* has on the learning curve.

To account for the role of practice, cognitive learning is calculated at three different points in time during the testing period (days 3, 4 and 5). However, the key cognitive learning metric focuses on the day 3 value, for which the largest sample is typically obtained.

3.12.4. Percentage change of scores

In a telephone conversation with the Lead Neuroscientist of the company that developed the cognitive app (L. Jacobson, personal communication 6 September 2017), it was confirmed that the percentage change metric is an appropriate tool to measure learning over time. The percentage change metric is used to compare the score obtained at a specific point in time and the first score ('**baseline').**

$$\Delta Lt = \frac{St - Sb}{Sb} \, x \, 100$$

S = score

S_b = baseline score

t = time

Cognitive learning is measured as the average percentage change of scores obtained in day 3 compared to day 1.

3.12.5. Selecting the baseline

Choosing the appropriate starting point is critical when drawing comparisons. As discussed with the Lead Neuroscientist of the team who developed the app (L. Jacobson, personal communication, 6 September 2017), two options are possible: using the first day score, or the second day score as baseline for calculating percentage increase. Jacobson suggested that playing the games for the first time can sometimes be considered as a ‘trial session’, with results omitted from the overall calculation.

However, this research assumes that learning process begins with the very first time when the cognitive games are played, and therefore the first scores can be used as baselines for the subsequent change. **The main body of analysis relies on percentage values calculated using the first scores as baseline.**

3.13.Data analysis strategy and tools

Descriptive statistics, graphical methods and inferential statistical tests (where applicable) were used for exploring the associations between predictors and outcomes.

3.13.1. Exclusion criteria

Participants were excluded from the main analysis dataset for any of the following reasons:

- The consent form was not signed;
- The Peak ID identification was not provided in the questionnaire answers;

- Demographic information was not provided;
- Questionnaire was completed fewer than three times;
- Outcome specific criteria (as explained below).

(B) THE COGNITIVE TESTS DATASET:

Exclusion criteria specific to the **cognitive learning outcome** focus on *when* and *how often* the Peak games are played. Firstly, the tests must be completed on the same days in which the survey is filled in; cognitive data that cannot be matched with a questionnaire was excluded, even if other days can be paired. The three days needed not necessarily be consecutive so long as the questionnaire/tests match was valid. If both the questionnaire and cognitive data are missing for one or several days, participants' remaining data could still be included in the dataset so long as there was a match for the remaining days. Secondly, to control for the effect of practice on cognitive learning, games must be only played once a day. If any game was played more than once in any of the study days, the data for that game was and excluded; results from the other games could still be included – in this case the average learning only considered the remaining games.

(C) THE WELLBEING DATASET:

Participants who did not complete the wellbeing section were excluded from the wellbeing data set. Exclusion from one of the two datasets is independent from the other. Participants who provided adequate cognitive and workspace data without completing the wellbeing section were included in the cognitive data set, and vice versa.

(C) PAIRING THE SURVEY AND COGNITIVE DATA

As explained in the previous section, pairing the workspace choice data to the cognitive results is essential, to ensure the relationship between the potential predictors and the measured outcomes was continuous. Establishing the three points in time when the survey and cognitive data need to match adds more complexity to the analysis process.

Pairing the survey data with cognitive data means different time frames are considered for each pair:

- In day 3, the cognitive learning achieved in day 3 compared to the baseline was paired with the values collected in day 3;
- In day 4, the cognitive learning achieved in day 4 compared to the baseline, was paired with the values collected in day 4;
- In day 5, the cognitive learning achieved in day 5 compared to the baseline, was paired with the values collected in day 5.

All values were computed based on the data available at each specific point in time. As not all participants completed the study for five days, different sample sizes were applicable for the three different timeframes.

3.13.2. Quantitative data: Statistical analysis strategy

To examine the relationship between choice of work space and time and learning (and the role of mediators) in more detail, statistical tests were used. There are two possible types of statistical methods that can be used to test the relationship between independent and dependent variables: parametric and non-parametric.

Parametric techniques require that the dependent variable measures meet the following criteria: are measured on an interval or ratio scale; approximate to a normal distribution; the variance between different groups of participants is homogenous (Foster et al., 2006). In contrast, non-parametric statistical techniques are “considered distribution free” (2006: 5), i.e. make no distributional assumptions about the population that the sample is drawn from. As such, they do not require that the sample observations are normally distributed. This is because non-parametric statistics rely on the *ranked values of the observations* instead of the actual observed measurements. By using ranks, these methods “gain robustness to the underlying distributions and the potential contamination of outliers" (Gao, 2010: 915).

As the distribution of the study outcome variable 'Cognitive learning' did not meet the normality assumption, using parametric statistical methods would be inappropriate as it would provide misleading results. Therefore, the analysis uses **nonparametric statistical tests** instead. These are used to statistically determine whether 'k' samples of observations are drawn from the same distribution (the null hypothesis posits that the distributions of the 'k' samples are identical). Depending on the study design and intentions, several tests are commonly used, such as the Wilcoxon signed rank test (for k=2 paired samples); the Mann-Whitney U test (k=2 independent samples), the Kruskal-Wallis test (k>2 independent samples) or the Friedman test (k>2 paired samples) (Gao, 2010; Schmidt, 2010).

Several nonparametric tests can be considered appropriate given the methodology of the WorQ study. The **Mann-Whitney U test** is a common nonparametric test for comparing two independent samples of unequal size (Gao, 2010; Hinton, 2010); it is considered a "useful test of small samples" (Hinton, 2010: 750). As the key relationship of interest – choice of work space and time and cognitive learning – involves *two samples of unequal size* ('high choice', and 'low choice', respectively), the Mann-Whitney U test is considered appropriate.

However, when the effect of mediators is considered, the number of samples becomes *greater than two*. For example, to test the mediating effect of workspace premise, several groups were formed, such as 'high choice – office building', 'low choice – office building', 'high choice – working from home', 'low choice – working from home', etc. In such cases, the independent samples **Kruskal-Wallis H test** is considered appropriate. Using the *ranks* of observations instead of the actual values, the test explores whether these ranks are equally distributed through the samples (Schmidt, 2010), i.e. whether at least one of the samples is different. It is considered "an alternative to the independent group ANOVA [analysis of variance], when the assumption of normality or equality of variance is not met" (Singh, 2007: 171). The Kruskal–Wallis test "can be recommended as a powerful distribution-free test" (Richardson, 2015: 938), however the consistency of the test is reduced when the overall shape of the samples are different (Schmidt, 2010).

Another aspect of interest is the potential within-sample effect of choice on learning, i.e. if the differences are ordered among classes. The **Jonckheere-Terpstra test for ordered alternatives** requires that the samples are arranged *ordinally* according to the variable of interest and tests if "the within-sample magnitude of the studied variable increases as we move from samples low on the criterion to samples high on the criterion" (Singh, 2007: 171). As the predictor variable – choice of work space and time – and some of the mediators (workspace IEQ and control) were measured using ordinal scales from 1 to 7, this test was considered adequate for exploring several aspects under investigation.

Finally, to gain further insights, the analysis also uses nonparametric **Median tests,** considered "a general alternative to the Kruskal-Wallis test" (Singh, 2007: 171). For these tests, the null hypothesis is that the medians are the same across the independent variable groups. Qualitative data: Thematic analysis strategy

The key purpose of qualitative content analysis is to answer the research question by 'making sense of the data', or locating meaning within the data (Guest et al., 2012b). A method frequently used in qualitative research is thematic analysis, defined by (Lapadat, 2012: 926) as below:

> "Thematic analysis is a systematic approach to the analysis of qualitative data that involves identifying themes or patterns of cultural meaning; coding and classifying data, usually textual, according to themes; and interpreting the resulting thematic structures by seeking commonalties, relationships, overarching patterns, theoretical constructs, or explanatory principles."

This method was chosen for the analysis of the qualitative content collected during the WorQ study with the objective of identifying themes or patterns related to the perceived effects of workspaces on productivity. The method used core concepts as described by Guest, MacQueen and Namey, (2014, p.50) :

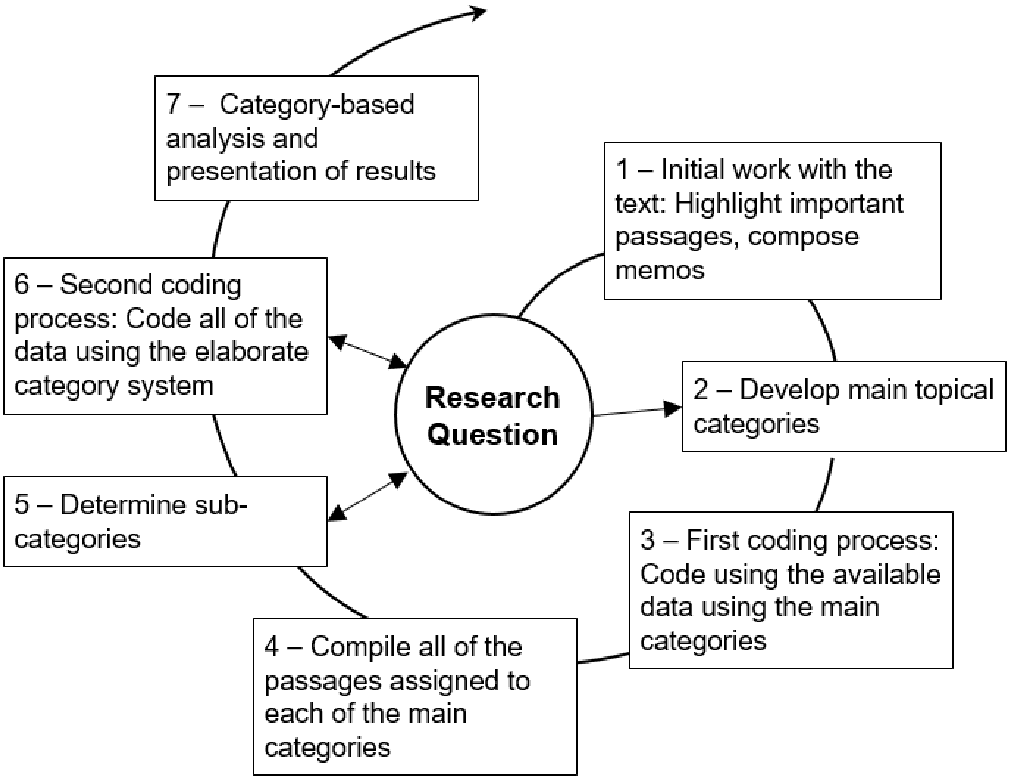
> "Data: The textual representation of a conversation, observation, or interaction.
> Theme: A unit of meaning that is observed (noticed) in the data by a reader of the text.
> Code: A textual description of the semantic boundaries of a theme or a component of a theme.
> Coding: The process by which a qualitative analyst links specific codes to specific data segments."

NVivo Pro 11 qualitative data analysis software (QSR International Pty Ltd, 2015) was used.

In contrast to the quantitative aspects measured in the WorQ study, the unit of qualitative analysis is the *account*. This represents participants' views on the workspace used in a particular point in time – the previous hour. As quantitative and qualitative data were gathered at the same time in the questionnaire, it was possible to code the accounts according to the type of workspace participants had used. To maximise the size of the sample, the analysis included *all accounts* belonging to identifiable participants who had signed the consent form.

The approach adopted in the WorQ study was broadly based on the one described by Kuckartz (2013) below.

Figure 3-4.Thematic Qualitative Text Analysis Process. Adapted from Kuckartz (2013: 70)



- **Categories and Cases**

As explained before, the questionnaire used two different questions to measure the *supportive* and *disruptive* effects of workspaces on productivity, with responses being stored in separate data subsets. The data were first classified according to either the ‘Support’ or ‘Disrupt’ categories that the text belonged to. The second step was the development of ‘Cases’ corresponding to the location and type of the workspace subjects had described in the two questions.

- **Subthemes**

After compiling the data assigned to each of the categories and code, subcategories were identified. Word frequency queries (WFQ) were used as a starting point to determine the key words used by participants to describe the supportive, and disruptive effects of the workspaces. Queries were set to search for the 100 most frequent words, with stemmed words grouping of results. The terms and concepts revealed by the two WFQs were developed into detailed subthemes appropriate for the research question. The text was read and coded accordingly.

- **Themes**

The second coding process involved second and third readings of the text. With each reading, the subthemes already identified were reviewed and finally grouped into broader themes.

- **Matrix coding**

While the quantification of qualitative data may be a ‘controversial topic’ (Guest et al., 2012a), it can also be considered a useful method to reveal patterns and frequencies within the data. Summary tables and Matrices can be used to describe the data in an unambiguous way. In the case of the WorQ study, matrix coding was used to explore the frequency of various codes across the workspace typologies.

Chapter 4. Results

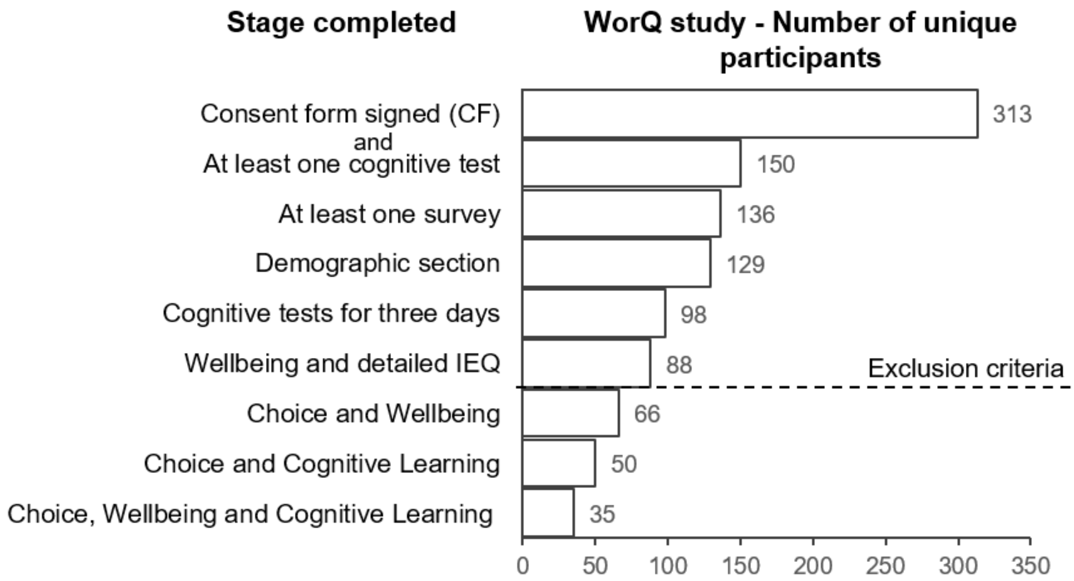
Chapter 4 presents the results of the *Workspace Choice and Quality study* ('WorQ'). The analysis is guided by a set of different objectives, explored in separate sections of this chapter. For ease of reference, the textbox below includes the headline findings, while the details are presented in the relevant sections.

Objective 1	**To assess the effect of choice of work space and time on productivity, conceptualised as cognitive learning.** **Key finding**: Choice of work time has a positive and significant effect on cognitive learning.	Section 4.3
Objective 2	**To assess the mediating effect of the workspace on the relationship between choice of work space and time and productivity, conceptualised cognitive learning.** **Key finding**: Control of workspace attributes is a significant mediator of the effect of choice on learning. Choice, workspace IEQ and control are significantly correlated.	Section 4.4
Objective 3	**To assess the effect of choice of work space and time on wellbeing.** **Key finding**: Choice of work space and time has a positive and significant effect on wellbeing.	Section 4.8
Objective 4	**To assess the mediating effect of the workspace on the relationship between choice of work space and time and wellbeing.** **Key finding**: Control of workspace attributes is a significant mediator of the effect of choice on wellbeing.	Section 4.9
Objective 5	**To explore workers' perceptions of what elements in the workspace support - and detract from – the ability to work productively.** **Key finding**: Eleven themes were identified: Noise, Space and layout, People, WiFi, IT & work technologies, Distractions, Meetings, Usability of furniture, Temperature, Light, lighting and views, Privacy, Personal aspects.	Section 4.11

4.1.The sample

Figure 4-1 presents the completion of the recruitment and data collection process. In total, email invitations were sent to 2,280 recipients, of whom 313 signed the consent form ('signed up'). Workspace rating and test completion rates decreased differentially during the observation period: some participants completed the tests but not the workspace ratings, or vice versa. While 136 participants completed at least one workspace rating, only 129 completed the demographic section, and 88 the wellbeing section. Similarly, of the 150 participants who started completing the cognitive tests, only two thirds (n=98) continued for at least three days.

Figure 4-1.The WorQ study sample: Participants at every stage



After applying the specific wellbeing and cognitive exclusion criteria as explained in the Methodology chapter (section 3.11.1), the final sample sizes discussed in this chapter are:

- Wellbeing results: N_W = 66, which represents 21% of the number of participants who signed up;
- Cognitive results: N_C = 50 (16%). A subset of these participants provided complete data for four or five days, rather than just those three; results are discussed in the Discussion chapter.

- Qualitative workspace productivity data: N_Q = 136 (43%).

Choice of work space and time data for three days were obtained for all participants whose cognitive and/or wellbeing results are discussed in the respective sections (N_C=50; N_W=66). Finally, 42 participants provided complete cognitive, wellbeing and IEQ results (13% of participants who signed up).

4.2. Overview of key variables: Predictors, outcomes and mediators

The causal pathway assumed by the WorQ study is that *choice of work space and time* acts as a predictor for the two independent outcome variables, namely *cognitive learning* and *wellbeing*, with the workspace acting as a mediator.

4.2.1. Choice of work space and time

All choice of work space and time data obtained in the testing period from participants who signed the consent form were collated, and 49 unidentifiable or duplicate observations were excluded. The sample is comprised of the remaining 408 unique observations obtained from 136 participants.

Choice of work space and choice of work time values are distributed differently, as shown in figures 4-2 and 4-3 and summarised in table B-1, Appendix B. While neither of the two distributions is normal, according to visual inspection and confirmed by Kolmogorov-Smirnov tests, they describe different patterns.

The choice of work space distribution shows that most responses are concentrated towards the extremes of the scale, corresponding to ‘full’ and ‘no’ choice. In contrast, the choice of work time values are more evenly distributed across the scale. This suggests participants perceive having **higher degrees of choice of *where* they work than over *when* they work**.

Figure 4-2. Choice of work space in the WorQ sample (N=136, 408 observations)

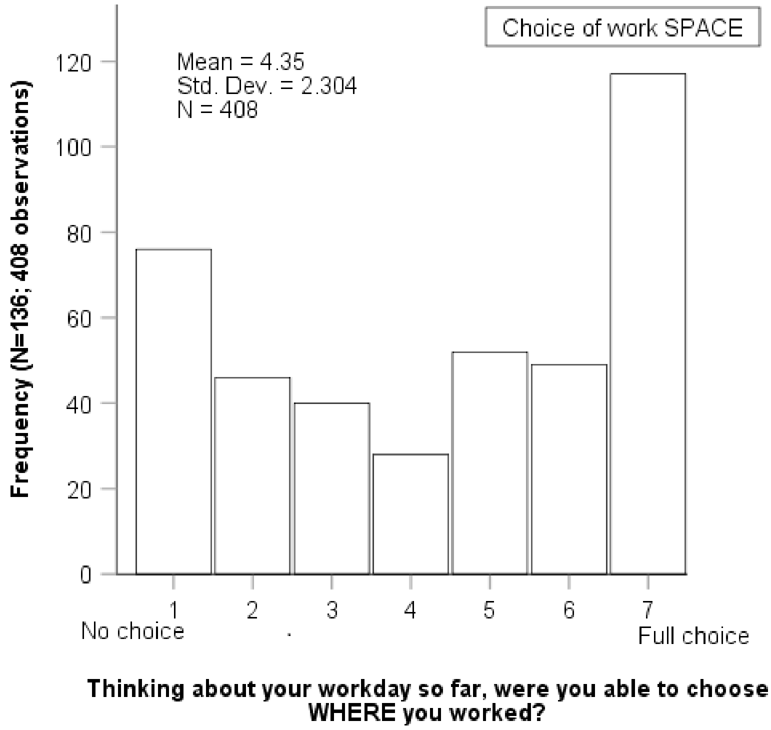
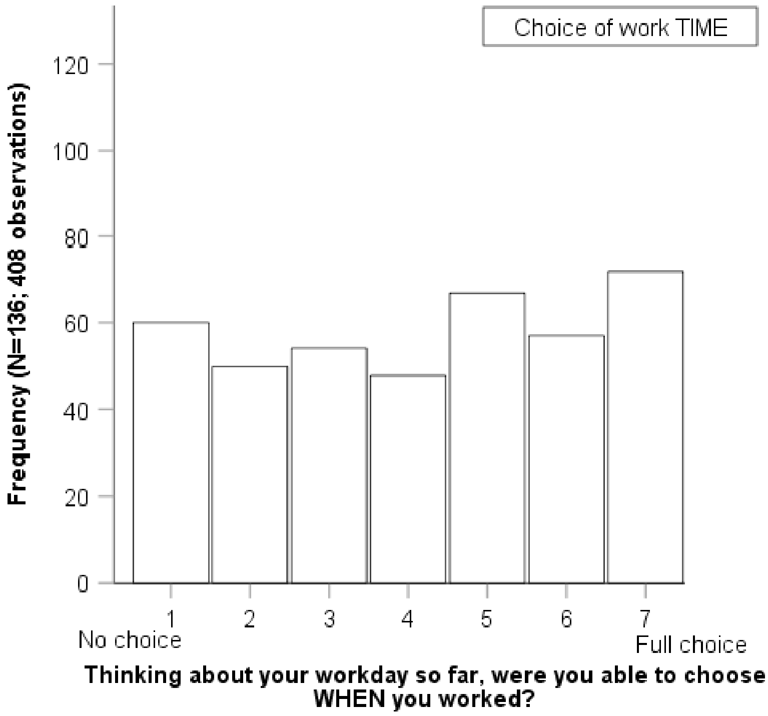


Figure 4-3. Choice of work time in the WorQ sample (N=136, 408 observations)



4.2.2. Cognitive learning

(A) ABSOLUTE VALUES: COGNITIVE TEST SCORES (DAYS 1 TO 3)

As described earlier in figure 4-1, 98 participants completed the cognitive testing aspect of the study protocol, i.e. completed at least three cognitive tests daily for at least three days. Of these, 48 participants did not complete a sufficient number of WorQ workspace ratings and were excluded from the cognitive tests sample. The current section explores the similarities and differences between the cognitive scores obtained by participants included in the cognitive tests sample (N_C=50) and by those excluded from this sample (N_{EX}=48). The analysis focuses on the **absolute values** of the scores obtained at the four cognitive tests.

In total, 1,170 scores were obtained by the 98 participants by completing the four cognitive tests once daily for three days. Tables B-2 and B-3 (Appendix B) show the descriptive statistics of the scores obtained at the four cognitive tests BAB, TCR, TUN and UNI.

SAMPLE SIZE AND SCORE RANGES

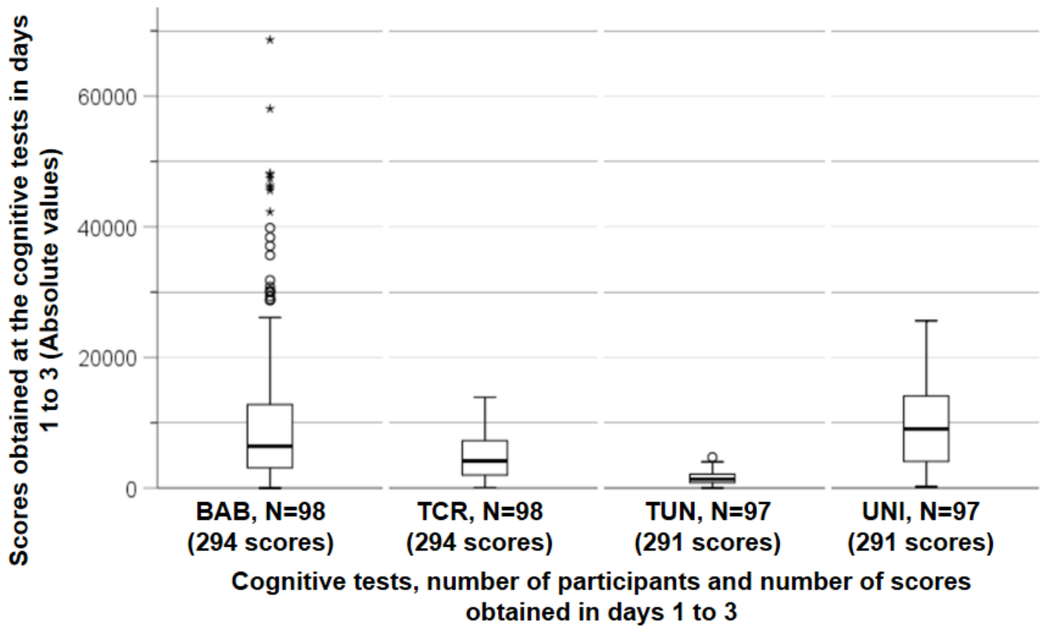
While most participants (n=96) completed all four tests, two participants missed one of either TUN, or UNI test. Therefore, the BAB and TCR tests' samples include 294 scores each, while for TUN and UNI, 291 scores each.

If all scores are plotted on the same chart using a scale from 0 to 70,000 on the vertical axis – as in figure 4-4 below – the distributions of the four tests only overlap on an interval of 0 to approximately 5,000 (to the highest value of the TUN test). This shows that scores obtained at each of the four cognitive tests differ significantly from each other. Although none of the distributions are normal[19], with longer tails towards the right - which suggests frequencies decrease as values increase - different patterns

[19] This was confirmed by statistical analysis using nonparametric Kolmogorov-Smirnov tests, significance: 0.000 for BAB, TCR, and UNI, and 0.003 for TUN.

can be observed.

Figure 4-4. Scores obtained at the four cognitive tests (absolute values) in days 1 to 3



- The **BAB test (word fluency and working memory)** has the overall broadest range of scores (68630), lowest minimum (0) and highest maximum value (68630) and mean (10006). The distribution includes the highest number of extreme values or 'outliers': twenty, which represents 7% of all BAB scores. Accordingly, the BAB scores have the highest variance of the four tests (110798881), and the highest StDev (10526), as summarised in table 4-1.

- The **UNI test (visual attention and visual recognition)** generated the second broadest range of scores (25410) and maximum score, the highest minimum (210), and median (9050), and the highest quartile values. The variance and StDev are the second highest (after BAB); values have considerable distance from the mean (table 4-1).

- Scores obtained at the **TCR test (task shifting and response control)** have the third broadest range (13800), third highest mean, median, maximum and minimum values, as well as the third highest variance and StDev (table 4-1).

- The **TUN test (working memory, sustained attention and visual recognition)** produced the narrowest range of scores (4687), and lowest mean, median, and quartile values (table 4-1). These figures, the variance and StDev values – 839511, and 916, both lowest of the four tests – suggest the TUN scores are concentrated closer to the mean of their distribution.

These differences are likely to be the result of different scoring algorithms used by the four tests.

Table 4-1.Descriptive statistics of the scores obtained at the four cognitive tests in days 1 to 3

Statistic		BAB	TCR	TUN	UNI
	Valid	294	294	291	291
	Missing	0	0	3	3
Mean		10006	4847	1500	9474
Std. Error of Mean		614	201	54	349
Median		6410	4150	1372	9050
Mode		2340[a]	10450	2279	10500
Std. Deviation		10526	3444	916	5957
Variance		110798881	11860715	839511	35489061
Range		68630	13800	4687	25410
Minimum		0	100	30	210
Maximum		68630	13900	4717	25620
Percentiles	25	3083	2000	830	3960
	50	6410	4150	1372	9050
	75	12860	7263	2123	14100

a. Multiple modes exist. The smallest value is shown

RELATIONSHIP BETWEEN THE FOUR TESTS

Although the descriptive statistics of the four tests revealed considerable differences between them, regression plots suggested **scores obtained at the four games are correlated**, as shown in table 4-2 below. Of all the relationships, TUN and UNI have the highest Spearman's rho correlation coefficient (0.523, significant at the 0.01 level, 1-tailed). This suggests that participants scoring high on one of the tests tended to also score high on the other.

Table 4-2.Correlations between scores obtained at the four cognitive tests: Spearman's rho.

			BAB	TCR	TUN	UNI
Spearman's rho	BAB	Correlation Coefficient	1.000	.211**	.311**	.283**
		Sig. (1-tailed)		0.000	0.000	0.000
		N	294	294	291	291

		BAB	TCR	TUN	UNI
TCR	Correlation Coefficient		1.000	.442**	.471**
	Sig. (1-tailed)			0.000	0.000
	N		294	291	291
TUN	Correlation Coefficient			1.000	.523**
	Sig. (1-tailed)				0.000
	N			291	288
UNI	Correlation Coefficient				1.000
	Sig. (1-tailed)				
	N				291

**. Correlation is significant at the 0.01 level (1-tailed).

A possible explanation could be that the cognitive skills explored by both tests overlap partially. TUN tests working memory, sustained attention and visual recognition, while UNI tests visual attention and visual recognition. These two tests also correlate strongly with the TCR test (TCR - TUN: 0.442; TCR – UNI: 0.471, both significant at the 0.01 level), which tests task shifting and response control skills. While correlations with the language test BAB are statistically significant, they are the weakest ones overall. Within these, the strongest pair is once again found between two tests that explore overlapping cognitive skills: BAB, which tests word fluency and *working memory*, has the strongest correlation with TUN, which tests working memory, sustained attention and visual recognition (significance: 0.311).

EFFECTS OF REPETITION: THE LEARNING CURVE

Repetition has a statistically significant effect on the scores obtained at all four tests, as shown by statistical analysis[20] and the values in tables B-2 and B-3 (Appendix B).

- Figure 4-5 below shows the scores obtained at the four tests during the three days of testing. To explore the pace that learning occurred for each of the tests, a line was plotted with a dashed line through the daily medians - the ‘median learning curve’. The rationale of using median instead of mean values was to create a true representation of the distribution, which minimises the effect of outliers. All but one test

[20] Nonparametric Kruskal-Wallis tests performed for each test revealed distributions obtained in day 1, 2, and 3 are statistically different. The significance coefficients of the tests are 0.003 for BAB, and 0.000 for TCR, TUN and UNI.

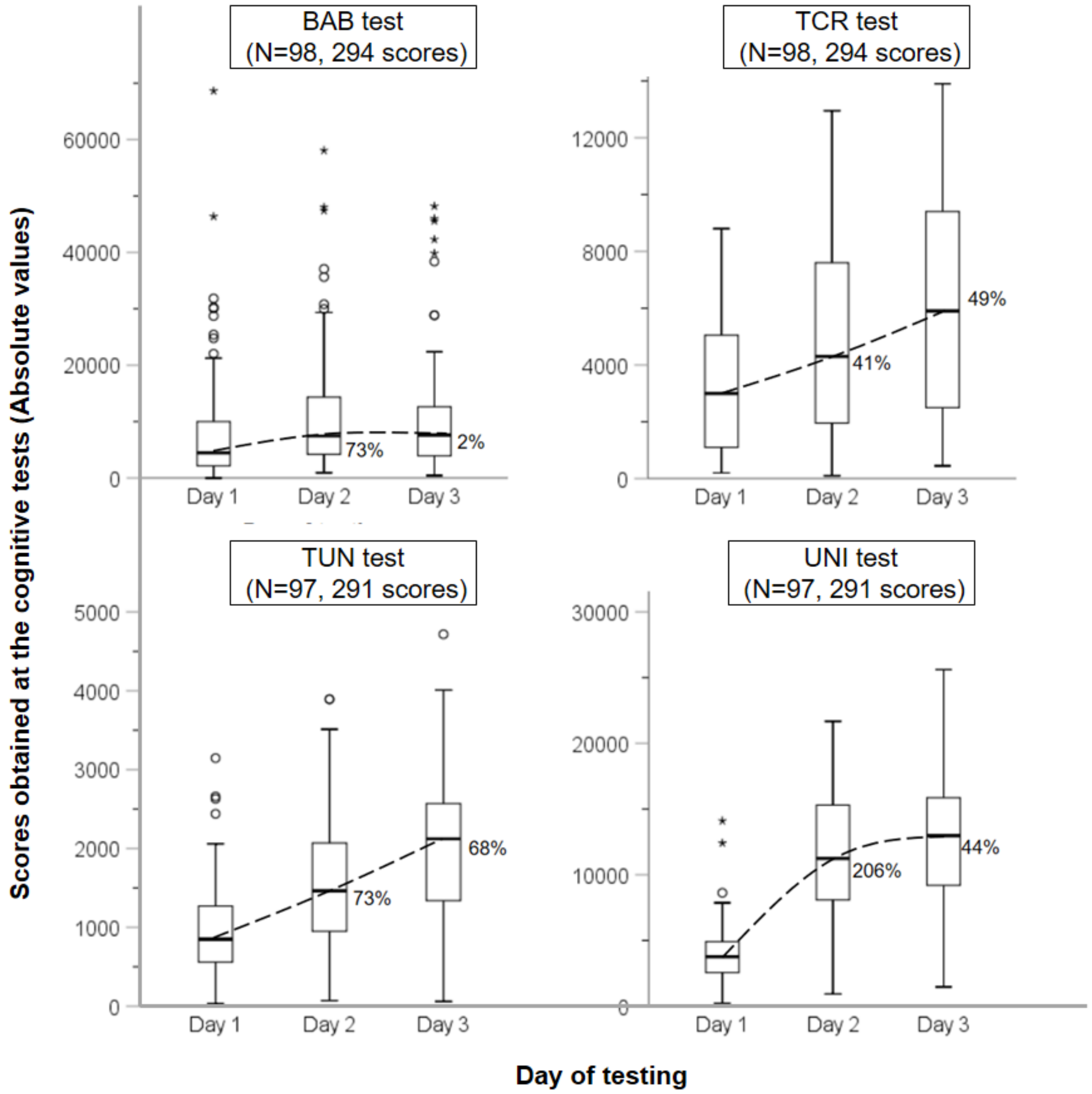
included such extreme values, with BAB including as many as twenty (7% of the data). A day-by-day percentage increase metric was calculated by dividing the difference between the current and previous day medians to the day 1 median, which is considered the baseline.

Firstly, **three of the four tests produced median learning curves that increase more from day 1 to day 2, than from day 2 to day 3**:

- The BAB test produced the ‘flattest’ median learning curve of the group. The steep 71% increase between day 1 and 2 medians is not sustained on the following days; between day 2 and 3, the median increase is 2%. Median cognitive learning over three days is 73%.
- The TUN test learning curve has similarly steep increases between day 1 and day 2 (73%), and day 2 and day 3, respectively (68%). Median cognitive learning over three days is 141%.
- The UNI test produced the steepest median increase from day 1 to day 2 (206%), and a reduced increase from day 2 to day 3 (44%). Median cognitive learning over three days is 250%.

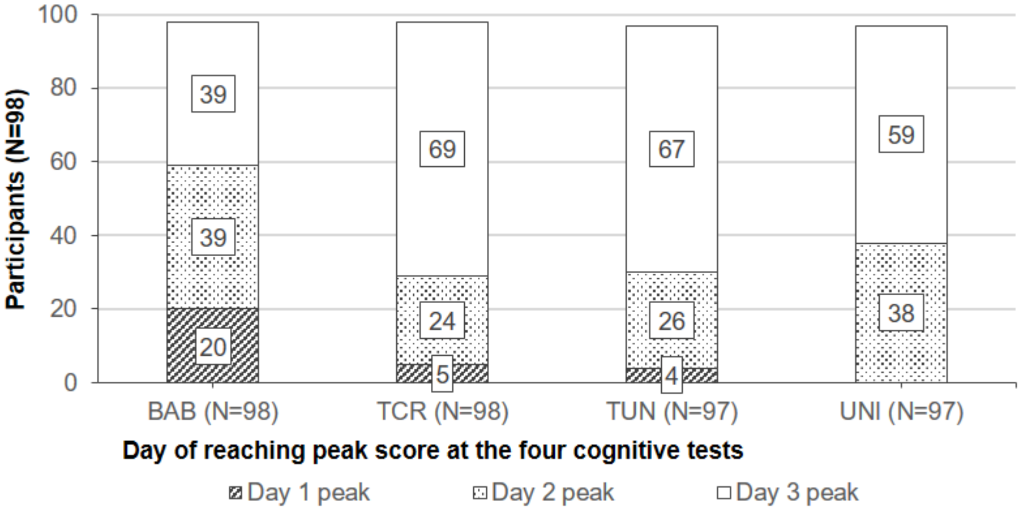
In contrast to the three tests above, the **TCR** day 1 to day 2 median increase (41%) was followed by a higher median increase from day 2 to day 3 (49%). Median cognitive learning over three days is 90%. The median cognitive learning of the four tests in day 3 (averaged) is 138%, and the mean (averaged) is 55%.

Figure 4-5. Cognitive test scores by testing day and median learning curves – first three days



While *most* peak scores were reached in day 3 at all four games, this was not always the case, as shown in figure 4-6. BAB test results (N=98) include the highest proportion of participants whose scores peaked on day 2 (n=39), and day 1 (n=20). In both cases, scores obtained *after* the peak score were lower. Therefore, a percentage change metric using the first score as a baseline will result in a negative value if the highest score was achieved on day 1.

Figure 4-6. Day of reaching peak scores at the four cognitive tests – first three testing days considered.

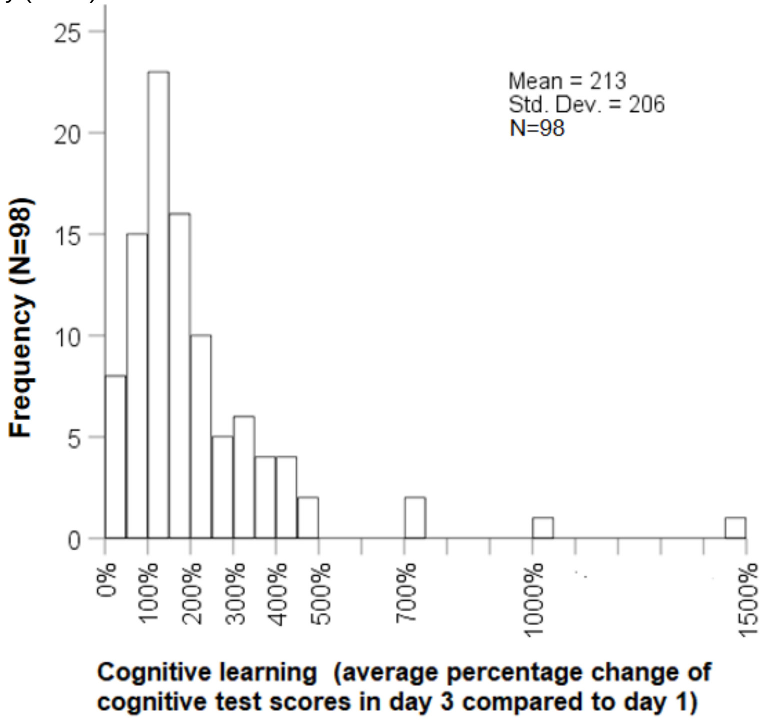


(B) COGNITIVE LEARNING VALUES

The previous section discussed the absolute values of the scores obtained from the 98 participants who completed cognitive tests once a day for three different days. This section concerns their cognitive learning outcome, which is operationalised as the averaged percentage change of the four cognitive test scores obtained in the third day compared to the first day.

While scores included in the average are sometimes negative, – i.e. are lower in day 3 than the day 1 baseline scores – the averaged percentage change values are all positive. This indicates that **all participants have achieved some degree of cognitive learning in day 3**, with values ranging from 2% to nearly 1500%; the mean cognitive learning value is 213% (table B-4, Appendix B). Visual inspection of the cognitive learning values histogram indicates the distribution is not normal; this is also confirmed by a one-sample Kolmogorov-Smirnov test. **The cognitive learning distribution is positively skewed, with most scores concentrated towards the lower end of the scale** (figure 4-7). Half of the scores are situated below the 153% value, and three quarters, below 256%. Four participants achieved changes higher than 500%.

Figure 4-7. Cognitive learning (average percentage change of cognitive tests scores in day 3 compared to day 1) in the WorQ study (N=98)



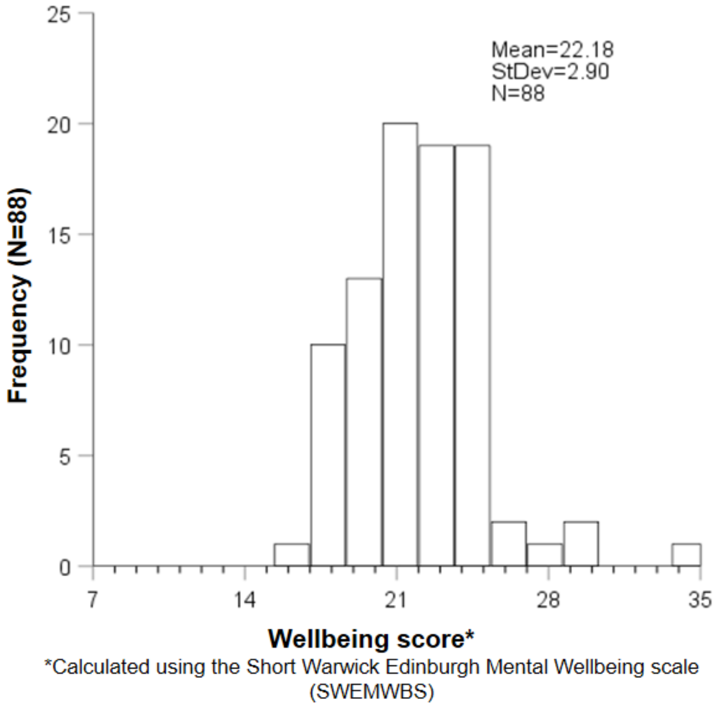
4.2.3. Wellbeing

Wellbeing results calculated using the Short version of the Warwick Edinburgh Mental Wellbeing scale (SWEMWBS) were obtained for 88 participants. Visual inspection of the histogram shown in figure 4-8 suggests the values are not normally distributed[21]. The data are characterised by the following parameters:

- Minimum = 16.88, above the lower end of the SWEMWBS scale, which is 7.00.
- Maximum = 35.00, which represents the maximum value of the scale;
- Mean = 22.18;
- Median = 21.95;
- Std. Deviation = 2.90;
- Percentiles: 25 = 19.98; 50 = 21.95; 75 = 24.11.

[21] Also confirmed by a one-sample Kolmogorov-Smirnov test (significance 0.023)

Figure 4-8. Wellbeing results obtained in the WorQ study (N=88)



4.2.4. Demographic information and Job control

Demographic information was obtained for 129 participants, as illustrated in figure B-1 (Appendix B) and summarised below.

- **Gender and Age**:

There are 68 male and 61 female participants in the sample (51% and 49% of total, respectively). With regards to age, over a third of the sample are in the 30-39 age group; distribution across the other age groups is relatively uniform:

  - 20 – 29: 26 participants (20% of total);
  - 30 – 39: 47 participants (36%);
  - 40 – 49: 28 participants (22%);
  - 50 – 59: 28 participants (22%).

Within each age group, the gender distribution is generally balanced, with similar proportions of male and female participants.

- **Education**[22]:

[22] Education is categorised according to participants' highest qualification level by using the framework used in England, Wales and Northern Ireland (UK Government, 2017).

There is an even distribution across the three levels of education, based on the highest level of qualifications completed by participants:

- Level 5 or lower - corresponding to A-levels, high school, apprenticeships or diplomas: 42 participants (33% of the sample);
- Level 6 – Bachelor's degree: 42 participants (33%);
- Levels 7 or 8 – Master's degree, Doctorate or other postgraduate degree: 45 participants (34%).
- Occupational Skill levels[23]:

The sample is predominantly comprised of participants whose occupations are classified as 'Highly skilled', i.e. 'Professionals' or 'Managers / Directors / Senior officials': 80 participants, representing 62% of the sample. The remaining 49 participants (38%) work in 'Lower- or upper middle' skill jobs, such as 'Associate professional / technical' or 'Administrative or secretarial' occupations.

- **Employment:**

Most participants in the sample are in full-time employment (n=109, or 85%); twelve are employed part-time (9%), and eight (6%) are self-employed or in other types of employment[24].

- **Industry**:

Participants are employed within the following sectors:

- Financial and insurance activities: 39 participants (30%);
- Professional, scientific and technical activities: 34 participants (26%);
- Real estate activities: 32 participants (25%);
- Administrative & support service activities: 15 participants (12%);
- Education: 4 participants (3%)
- Other industries: 5 participants (4%).

[23] Occupational skill level is categorised based on their occupation and follows the guidelines of the Standard Occupational Classification (SOC) 2010 (ONS, 2010) and data on employment and skill level in the UK (ONS, 2016)

[24] While self-employed participants could also work on a part-time basis, type of employment and numbers of hours worked were not measured separately.

Within the ‘Financial and insurance’ subgroup, the proportion of part-time employees is slightly higher than in the other groups (n=6, or 15% of the subgroup); similarly, two of the fifteen ‘Administrative & support service’ workers (13%) work part-time. Self-employment or other types of employment are more prevalent among the ‘Professional, scientific and technical’ workers (n=3, or 8% of the group) and ‘Real estate’ sector participants (n=2, 6%).

- **Language**:

The sample is comprised of 111 participants (86%) whose first language is English. The remaining eighteen (14%) are not native English speakers.

- **Job control**:

Most participants stated having relatively high levels of job control: 99 of the 129 participants in the sample (77%) chose values of 5 or higher out of a possible 7. This includes 22 (17%) who stated having ‘Full control’. In contrast, only one participant stated having ‘No control’ over their job.

4.2.5. The workspace

(D) PREMISES AND TYPES

During the observation period, participants[25] worked in their office building, in their homes, or in other premises. As summarised in figure B-2 (Appendix B) and below, the sample size for each type of premise is different:

- The office building: n=130, 324 observations, which represents 79% of the sample;
- Home working: n=37, 59 observations (15%);
- Other premises: n=21, 25 observations (6%).

Within each of these premises, different workspace types are used (figure B-3, Appendix B). **In the office building**, the most frequently used workspace type is the

[25] The sample is comprised of the remaining 408 unique observations obtained from 136 participants.

open plan office (OPO), which represents 73% of the total sample. This includes participants who used permanently assigned desks (OPO-AD, 43% of the total sample), or hot desking (OPO-HD, 30%). The remaining 6% of the office building group includes enclosed offices either shared (EOS, 4%) or private (EOP, less than 1%), or meeting spaces (MS, 2%). Within the **home working** group, participants used desks or tables located in living areas (7% of the sample), or the bedroom (3%), or enclosed home offices (5%). Work premises categorised as '**other**' include working in external office buildings (usually in meeting spaces), coffee shops or, less frequently, public transport (trains and the airport).

(E) OVERALL WORKSPACE IEQ AND CONTROL OF ATTRIBUTES

An overview of the values collected for the workspace IEQ and control of attributes variables is presented in table B-6 and figure B-4 (Appendix E). In general, participants in the sample reported high levels of satisfaction with the overall workspace IEQ. This is shown by the longer left tail of the distribution, and the relatively high values of the mean, median and mode (5.06, 5.00, and 6.00, respectively). In contrast, values for control of workspace attributes are more uniformly distributed across the seven steps of the scale. The mean, median and mode of control have different values (3.82, 4.00 and 2.00, respectively). Values of 1 ('No control') and 2 were reported by a quarter of the respondents.

4.3. Choice and Cognitive learning - The WorQ cognitive tests sample (N_C=50)

This section presents how the first analysis objective was reached:

Objective 1	To assess the effect of choice of work space and time on cognitive learning. **Key finding**: Choice of work time has a positive and significant effect on cognitive learning.

After applying the specific exclusion criteria related to the cognitive outcome (as shown in section 3.11.1.), the size of the sample was considerably reduced. Complete results were obtained from **50 participants who provided matching workspace ratings and cognitive data for three consecutive days** (‘the cognitive tests’ sample). The relationship between choice and the cognitive learning outcome is discussed based on the following data:

- 150 workspace ratings completed in days 1, 2 and 3;
- 582 cognitive scores obtained in days 1, 2 and 3.

4.3.1. Choice of work space and time

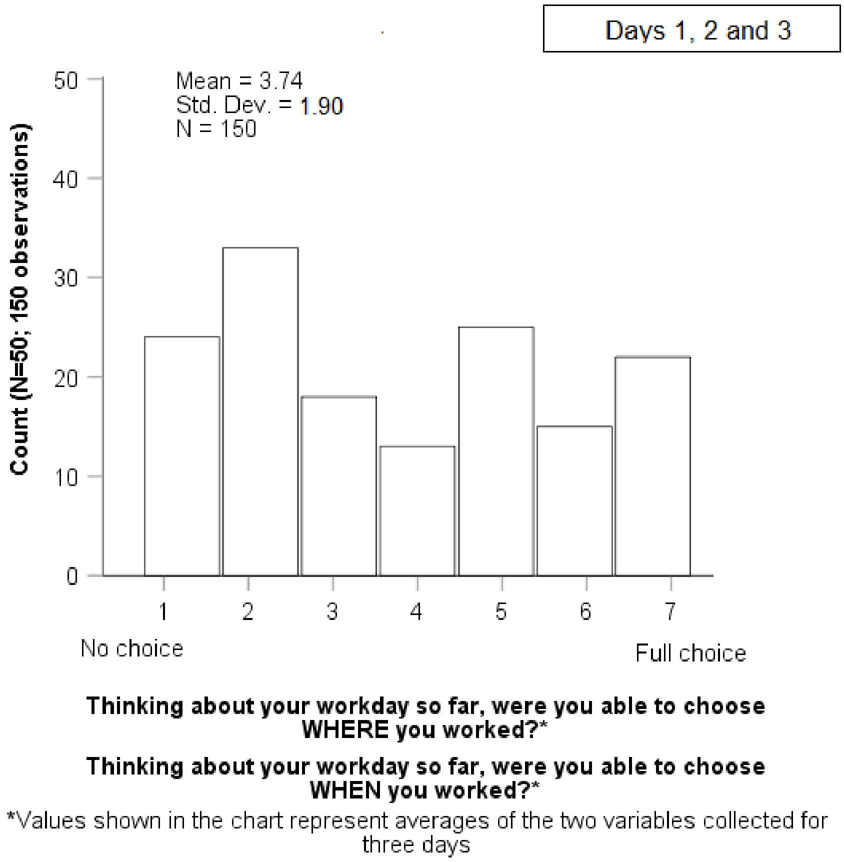
(A) SAMPLE OVERVIEW

The distribution of choice of work space and time values collected in the cognitive tests sample during the first three observation days is non normal, as suggested by visual inspection (figure 4-9) and confirmed by Kolmogorov-Smirnov statistical tests. As shown in table B-7 (Appendix B) results are consistent with the sample overview described earlier. However, **the choice of work space and time values are situated somewhat lower on the scale**:

- Mean: 3.74 compared to 4.25 in the general sample;
- Median: 3.75 compared to 4.50;
- Mode: 2.00, compared to 7.00;
- 75th percentile: 5.13, compared to 6.00.

Consistent with the general sample findings, choice of work space and choice of work time distributions are non normal and describe different patterns. The **choice of work space** distribution is polarised, with nearly half of participants selecting the two values furthest from the mean, representing ‘no choice’ (27% of the data) and ‘full choice’ (19%). In contrast, the **choice of work time** values are more evenly distributed: values of 2, 4 and 6 have almost identical frequencies. The ‘full choice’ option is the least frequent: only seven participants chose the ‘full choice over when work is performed' option during the observation period (9%).

Figure 4-9. Choice of work space and time (average) in days 1 to 3 in the cognitive tests sample (N_C=50; 150 observations)



Perceptions of choice of work space and time are strongly correlated.

The data collected during the observation period in the cognitive sample correlate significantly at the 0.01 level, Spearman's *rho* coefficient is 0.633 (table 4-3).

Table 4-3. Correlation of choice of work space and time in the WorQ cognitive tests sample

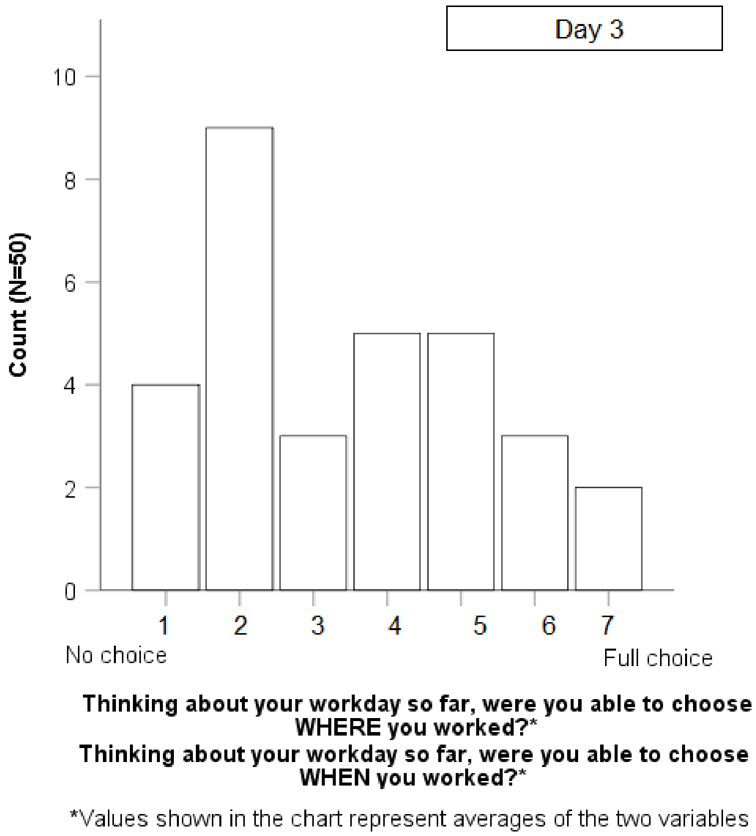
		Choice of work time
Choice of work space	Spearman's rho	0.633**
	Sig. (2-tailed)	.000
	N	150

**Correlation is significant at the 0.01 level (2-tailed).

(B) DAY 3 VALUES

As suggested by visual inspection and confirmed by statistical tests, the choice of work space and time values collected in day 3 are not normally distributed (figure 4-10).

Figure 4-10. Choice of work space and time in day 3: Distribution of values in the WorQ cognitive tests sample (N=50)



As before, **choice of work space and time collected in day 3 are correlated** (Spearman's *rho* coefficient: 0.714, statistically significant at the 0.01 level), and their distributions describe different patterns. While both variables included the 'no' and 'full' choice values, the choice of time distribution is generally situated lower on the scale than the choice of space variable.

Table 4-4. Choice of work space and time in day 3: Descriptive statistics of WorQ Cognitive tests sample (N=50)

		Choice of work space and time in day 3 (average)	Choice of work space in day 3	Choice of work time in day 3
N		50	50	50
Mean		3.81	3.84	3.78
Median		4.00	4.00	3.00
Mode		2.00	1.00	3.00
Std. Deviation		1.87	2.21	1.81
Minimum		1.00	1.00	1.00
Maximum		7.00	7.00	7.00
Percentiles	25	2.00	2.00	2.00
	50	4.00	4.00	3.00
	75	5.50	6.00	5.00

The median and 75th percentile values – both of which are higher for choice of work space compared to choice of work time (table 4-4) **– suggest that participants in the WorQ cognitive tests sample were more likely to be able to choose *where* they worked than *when* they worked.**

Two ‘choice of work space and time’ groups of comparable size are defined based on the median value of 4.00; this is also the value closest to the mean (3.81).

- The ‘high choice’ group: n=27 participants whose choice of work space and time values are at or above the median in day 3;
- The ‘low choice’ group: n=23 participants whose CST values in are below the median in day 3.

This categorisation is used to explore relationships between the variables of interest, as shown in the following sections.

4.3.2. Cognitive learning

(A) DAY 3 VALUES

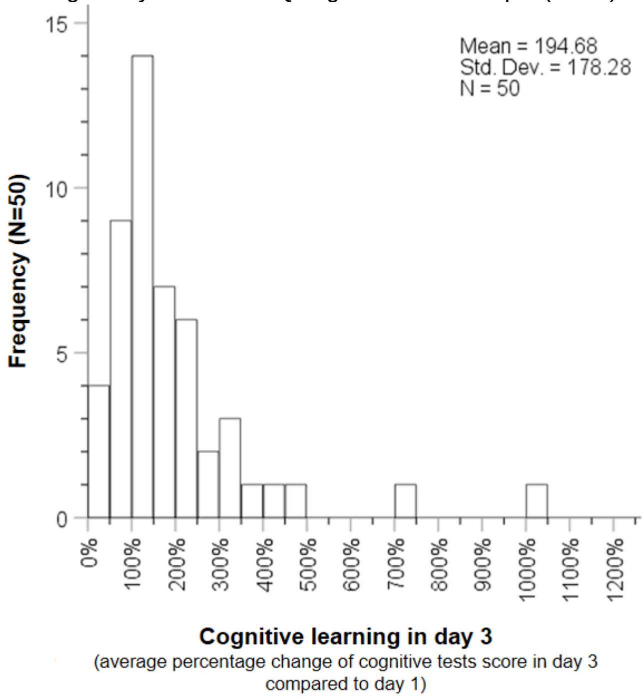
The distribution of cognitive learning values is positively skewed; visual inspection (figure 4-11) and statistical analysis using the nonparametric Kolmogorov-Smirnov test confirmed the distribution is not normal. The range is situated between two positive values: 12 (Min) and 1,047 (Max), with a mean of 195 (table 4-5). **This shows that all participants in the sample improved their scores on the cognitive tests in day 3, compared to day 1**.

Table 4-5. Cognitive learning in day 3 in the WorQ cognitive tests sample: Descriptive statistics (N=50)

N	Valid	50
Mean		194.68
Median		145.50
Mode		80.00[a]
Std. Deviation		178.28
Minimum		12.00
Maximum		1047.00
Percentiles	25	98.00
	50	145.50
	75	220.75

a. Multiple modes exist: 80, 141 and 147.

Figure 4-11. Cognitive learning in day 3: The WorQ cognitive tests sample (N=50)

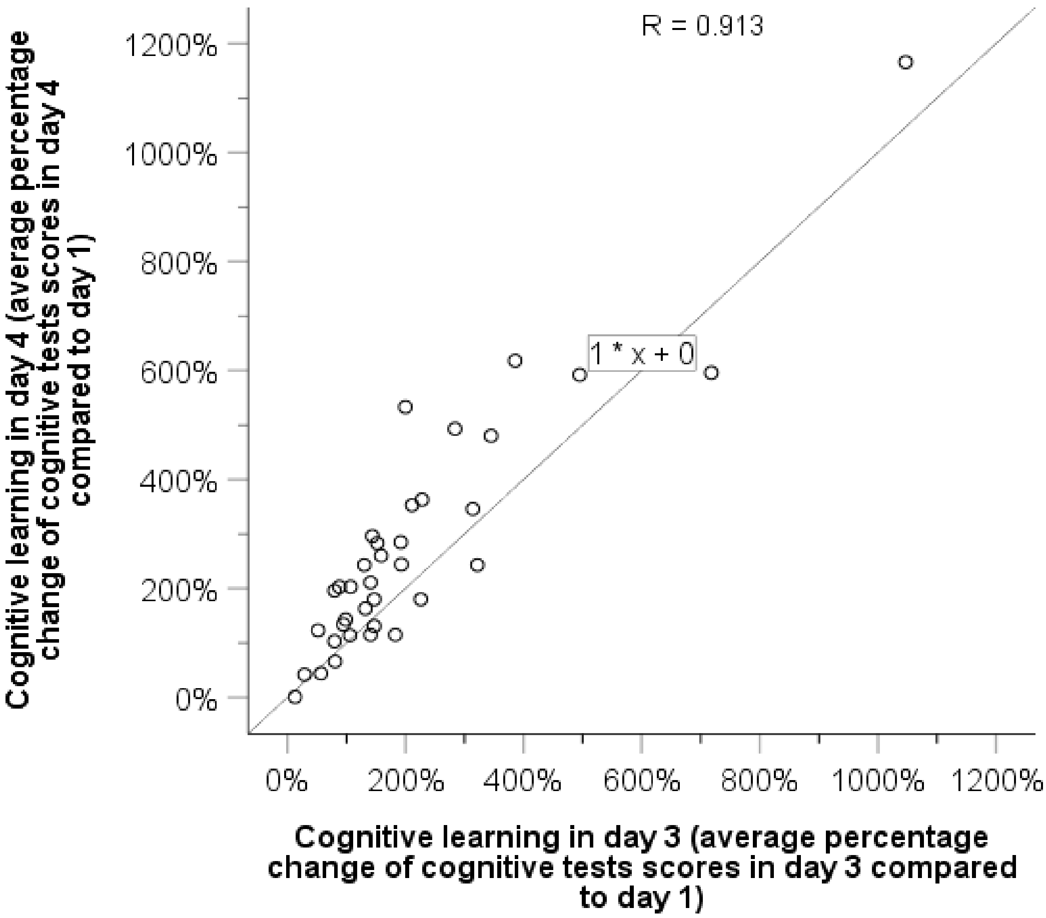


The longer right tail of the distribution shows that few participants achieved high values of improvement of their scores and many participants achieved lower improvement rates. As shown by the median value, half of the sample improved their scores by approximately 150%, but only a quarter achieved improvements above 220%. Only 5 participants (10% of the sample) improved their scores above 350%.

(B) EFFECTS OF REPETITION ON LEARNING

To explore the effects of time on cognitive learning, results for the 36 participants who completed the tests in both days 3 and 4 were regressed (figure 4-12). Cognitive learning values achieved in day 3 and 4 are linearly correlated, with an R-squared coefficient of determination of 0.913, which suggests the linear model explains 91% of the variability of the data around the mean; this was confirmed by a paired sample t-test. For a few participants, day 4 improvement values are lower than day 3 ones, however these are not common. As suggested by the correlation coefficients described above, ***repetition is generally associated with improvement of the cognitive scores***.

Figure 4-12. Cognitive learning in day 3 and day 4 in the WorQ Cognitive tests sample (N=36)

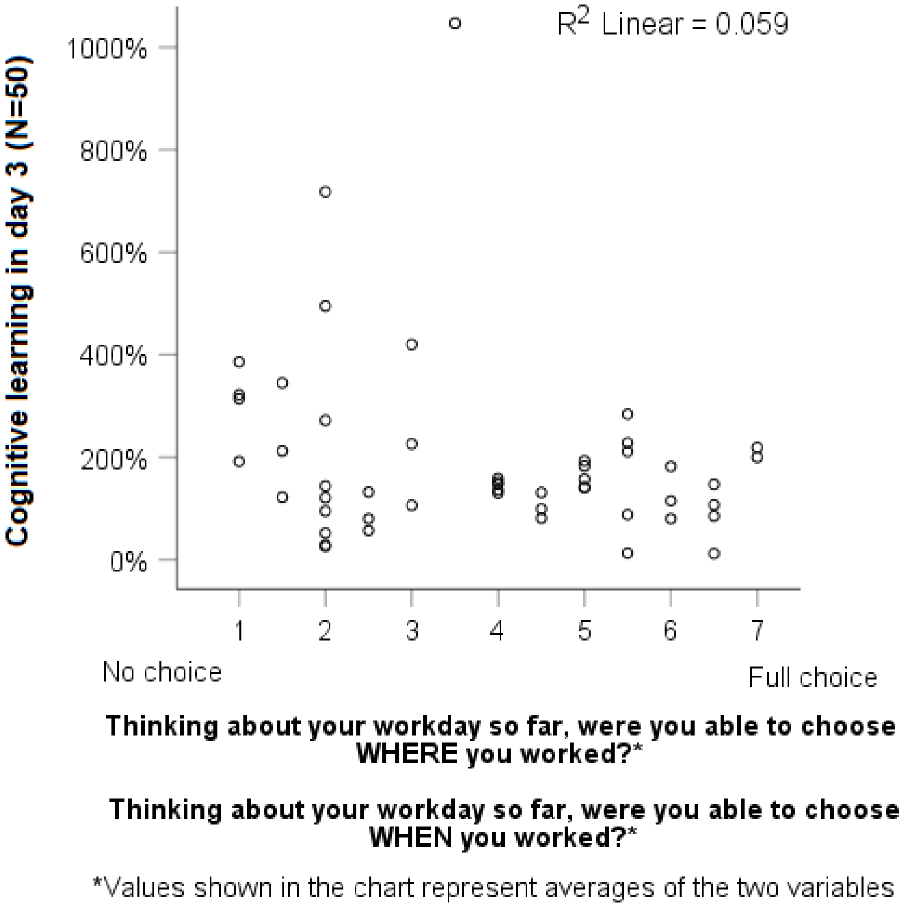


4.3.3. Choice and learning

The dynamics of the choice / learning relationship can be explored by regressing day 3 values of both (figure 4-13).

Visual inspection of the scatterplot in figure 4-13 reveals the relationship is **not likely to be linear**, as confirmed by the low R^2 coefficient. The figure also suggests that the direction of association between choice of work space and time and cognitive learning – *if at all present* – is unclear.

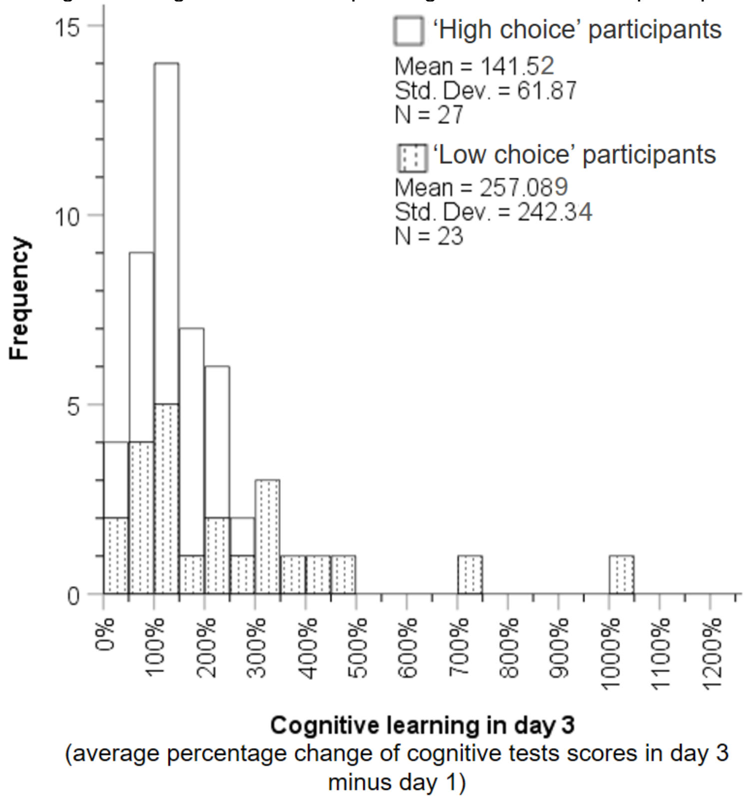
Figure 4-13. Choice of work space and time and cognitive learning in day 3 in the cognitive tests sample (N=50)



Furthermore, the stacked histogram in figure 4-14 shows that the cognitive learning values are distributed differently for participants with higher and lower levels of choice of work space and time, respectively.

Firstly, the spread of the cognitive learning values is narrower for ‘high choice’ participants than it is for ‘low choice’ participants. The latter category includes more diverse values, extending beyond the maximum values recorded from participants with higher choice. All five participants with the highest improvement of their scores (top 10% of the sample) are from the ‘low choice’ group.

Figure 4-14. Cognitive learning in the cognitive tests sample: 'High' and 'low' choice participants (N=50)



Secondly, as summarised in table 4-6 below, there are differences between the means and medians of the cognitive learning values obtained from participants who have 'high' and 'low' choice of work space and time. Both mean and median values are lower for the 'high choice' group than for the 'low choice' one.

Table 4-6 Cognitive learning in the cognitive tests sample - 'High' and 'low' choice participants: Descriptive statistics (N=50)

		Cognitive learning values: High choice participants	Cognitive learning values: Low choice participants
N	Valid	27	23
Mean		141.52	257.09
Median		141.00	192.00
Mode		141.00[a]	26.00[a]
Std. Deviation		61.87	242.34
Minimum		12.00	26.00
Maximum		284.00	1047.00
Percentiles	25	99.00	95.00
	50	141.00	192.00
	75	183.00	345.00

a. Multiple modes exist. The smallest value is shown

As suggested earlier (figure 4-14), there is more variation of the data around the mean in the 'low choice' group and the StDev is higher. Differences can also be observed by looking at the percentile values obtained in the two choice groups. While the lower quarter values are similar (99 for ‘high choice’ participants and 95 for the ‘low choice’ ones), the gap widens in the upper quartiles, with the ‘low choice’ group having higher values. **This suggests that participants with lower choice learned more than those with higher choice values.**

(A) STATISTICAL FINDINGS

No statistically significant difference was found between the cognitive learning values of participants with ‘low’ and ‘high’ choice of work space and time, respectively, or for the choice of work space variable (table 4-7). In contrast, **choice of work time is found to have a significant effect on learning** (row 3).

Table 4-7. Statistical test results: Choice of work space and time and cognitive learning in the cognitive tests sample (N=50)

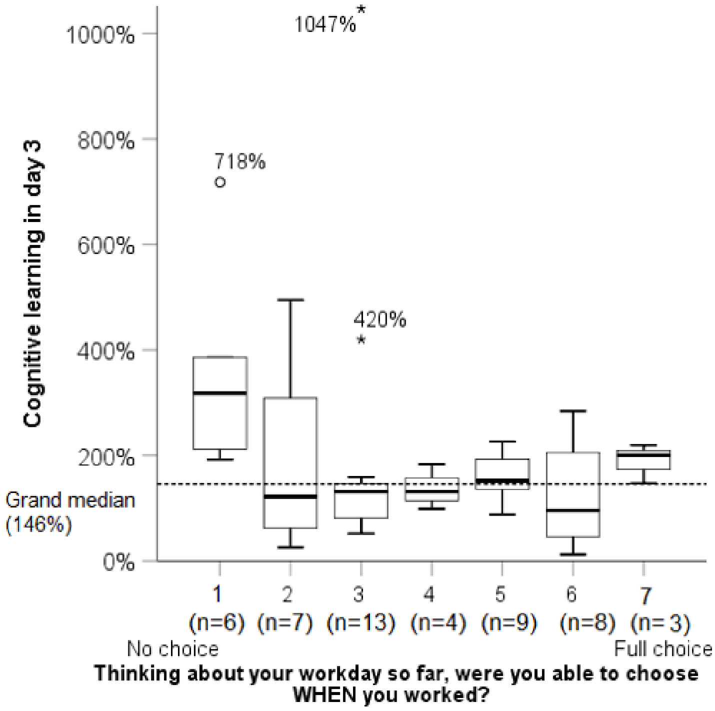
No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result	Significance
1	Choice of work SPACE and TIME	—	Cognitive learning	Median Test	Retain	1.000
				Mann-Whitney	Retain	0.186
2	Choice of work SPACE	—	Cognitive learning	Median Test	Retain	0.799
				Jonckheere-Terpstra	Retain	0.211
3	Choice of work TIME	—	Cognitive learning	Median Test	Reject	0.048*
				Jonckheere-Terpstra	Retain	0.236

***Statistically significant at 0.05 level.**

Null hypotheses (H0) for independent samples tests:
Median Test H0: The medians of [dependent variable] are the same across categories of [independent and mediator variable]. Mann-Whitney, Kruskal-Wallis and Jonckheere-Terpstra H0: The distributions of [dependent variable] are the same across categories of [independent and mediator variable].

Ordering the learning results according to the choice of work time variable reveals how the two may be related (figure 5-14). The median learning values appear to increase proportionally for the 36 participants with choice values of 2, 3, 4, 5 and 7, respectively, suggesting that participants with higher choice of time levels tend to have higher cognitive learning scores. The ranges and minimum values tend to be situated increasingly higher on the (vertical) cognitive learning axis for participants with increasingly higher choice of work time (horizontal axis). Excluding the outliers, there is no overlap between participants who had choice levels of 3, and 7. Also, median learning values for participants with choice values of 5, and 7, respectively, are the only ones that are higher than the overall median. However, participants with choice of time values of 1 and 6 (n=14 in total) contradict this apparent pattern, suggesting the observed effect could be the result of a sampling error. Each choice of work time subgroup has a different size, which limits the robustness of the comparison.

Figure 4-15. Choice of work TIME and cognitive learning in day 3 in the cognitive tests sample (N=50)



4.4.Choice, the workspace, and cognitive learning in day 3

This section presents the results related to the second research objective:

Objective 2	To assess the mediating effect of the workspace on the relationship between choice of work space and time and cognitive learning. **Key finding**: Control of workspace attributes is a significant mediator of the effect of choice on learning. Choice, workspace IEQ and control are significantly correlated.

4.4.1. Workspaces used in the WorQ cognitive tests sample

(A) PREMISES AND TYPES

OVERVIEW OF THE COGNITIVE TESTS SAMPLE

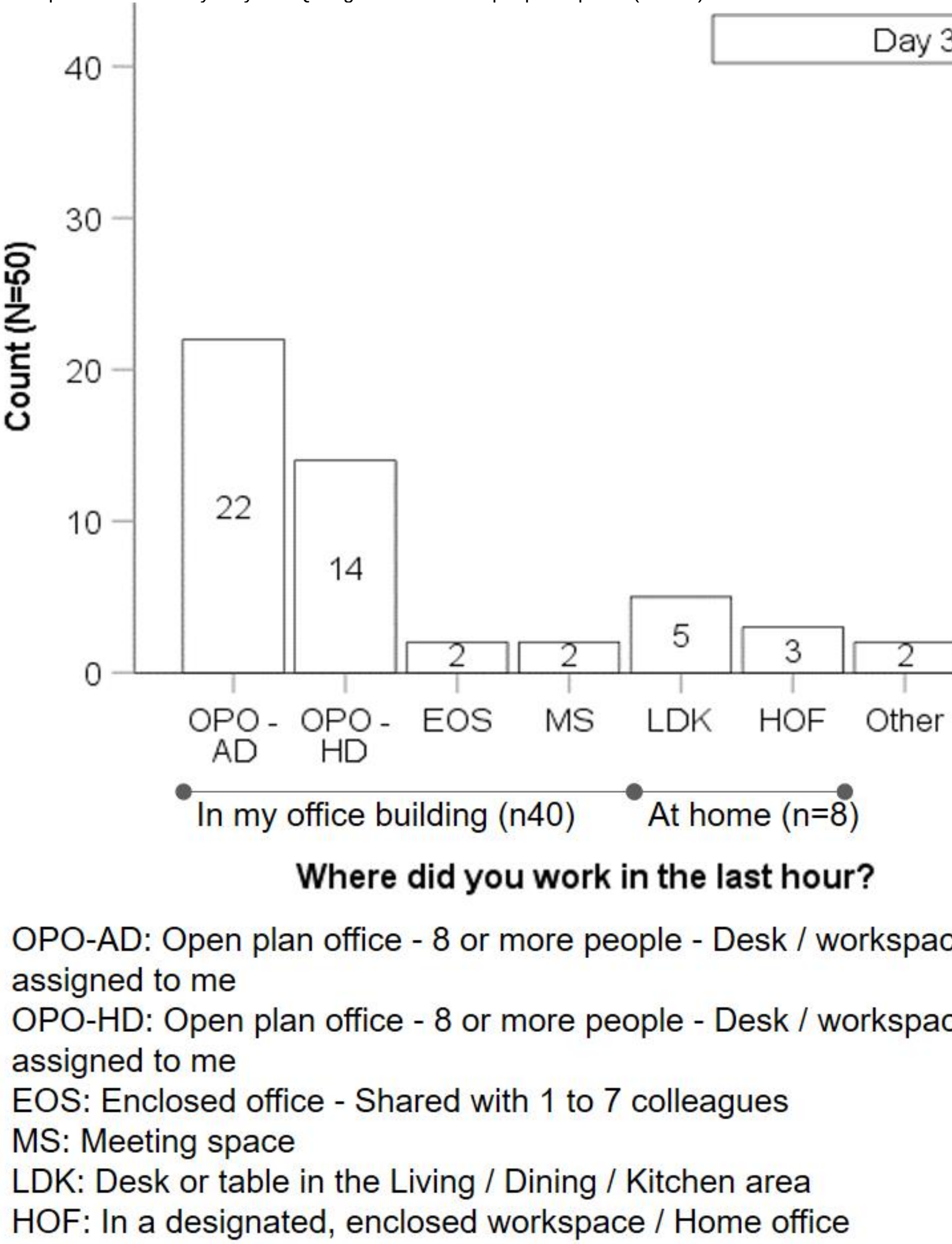
Most of the results collected in the WorQ cognitive tests sample are obtained from office building users (figure B-5, Appendix B). During the three testing days, 47 participants completed 126 workspace ratings that refer to work settings located within their office buildings (84% of workspace ratings). **This means that nearly all participants in the cognitive sample (94% of participants) worked in their office building at least once during the three days**. Ten participants also worked from home (fourteen workspace ratings), and eight used other premises (ten workspace ratings).

The majority of workspace ratings were completed in **open plan office** settings (117 workspace ratings, or 78%, completed by 46 participants. Most open plan office workers used desks *permanently assigned to them* (78 workspace ratings from 31 participants), and others used *hot desks* (39 workspace ratings from 18 participants); some participants used assigned and unassigned desks in different days. Other work settings located within office buildings include *enclosed, shared offices* (seven workspace ratings from six participants), and *meeting spaces* (two workspace ratings from two participants). When **working from home**, participants worked at desks or tables in their *living, dining or kitchen areas* (nine workspace ratings from six participants); *enclosed and designated workspaces i.e. 'home offices'* (four workspace ratings from four participants); or desks or tables located in their *bedroom* (one participant) (Figure B-6, Appendix B).

WORKSPACES USED IN DAY 3

In day 3, **40 participants worked in office buildings, eight worked from home, and two in other work settings.** Figure 4-16 shows that participants who worked in office buildings primarily worked in open plan offices (72% of the sample, n=36 in total), either using *desks permanently assigned to them* (n=22), or *desks not assigned to them* (n=14). Fewer participants worked in *enclosed offices shared* with 1 to 7 colleagues (n=2) or in *meeting spaces* (n=2). Participants who worked from home in day 3 used *desks or tables in the living, dining or kitchen areas* (n=5), or *designated, enclosed workspaces or home offices* (n=3).

Figure 4-16. Workspaces used in day 3 by WorQ Cognitive tests sample participants (N_C=50)



(B) OVERALL WORKSPACE IEQ AND CONTROL OF ATTRIBUTES

OVERVIEW OF THE COGNITIVE TESTS SAMPLE

The Workspace IEQ and control of attributes values collected in the cognitive tests sample describe non-normal distributions, as suggested by visual inspection (figures B-7 and B-8, Appendix B) and confirmed by nonparametric tests. The descriptive statistics of the two variables show different patterns, with **workspace IEQ being defined by higher values than workspace control:**

- Workspace IEQ mean (4.88), median (5.00), and mode (5.00) values are higher than those of workspace control (3.44; 3.50; and 1.00, respectively);
- Percentile values are also higher for IEQ than for control:
    - 25th percentile: 4.00 for IEQ, compared to 2.00 for workspace control;
    - 50th: 5.00 compared to 3.50;
    - 75th: 6.00 compared to 5.00.

This suggests that participants in the cognitive tests sample generally **perceived they used workspaces that were satisfactory, and that they had little control over.**

However, there is a relationship between the two variables. Nonparametric tests found that **Workspace IEQ and control of attributes are correlated** (Spearman's rho= 0.570, statistically significant at the 0.01 level).

A suggested association was found between the degree of choice of work space and time, workspace quality and control, as shown by the Spearman's rho coefficients of the tests, which are marked as statistically significant at 0.01 level:

- Choice of work space correlates with workspace IEQ (0.439) and control of attributes (0.395);
- Choice of work time correlates with workspace IEQ (0.495) and control of attributes (0.476).

When exploring the mean values obtained from participants who worked in different premises, certain patterns may become apparent. As summarised in table 4-8 below, perceptions of both IEQ and control of attributes are higher when working from home than in the office building. While these may be a result of the different sample sizes, Kruskal-Wallis statistical tests found **the distributions of workspace control of**

attributes values obtained from different premises are significantly different. The effects of workspace premise on perceived IEQ values were not found statistically significant, despite the correlation between IEQ and control, described above. **Workspace type** also appears to be associated with different values of IEQ and control (table B-8, Appendix B). Among open plan office workers, participants who used *hot desks* reported higher workspace IEQ and control of attributes than workers who used *permanently assigned desks*. **Statistical tests**[26] **found the differences to be significant for perceived workspace control**, but not for perceived IEQ.

Table 4-8. Workspace IEQ and control of attributes by premise in the cognitive tests sample (N=50; 150 observations)

Workspace premise		Workspace IEQ	Control of workspace attributes
Home working	Mean	5.36	5.64
	N	14	14
	Std. Deviation	1.55	1.50
Office building	Mean	4.89	3.34
	N	126	126
	Std. Deviation	1.32	1.90
Other	Mean	4.10	1.60
	N	10	10
	Std. Deviation	1.92	1.07
Total	Mean	4.88	3.44
	N	150	150
	Std. Deviation	1.39	1.99

DAY 3 VALUES

Descriptive statistics for the workspace IEQ and control of attributes values obtained in day 3 are summarised in table 4-9 below and figures B-9 and B-10 (Appendix B).

Table 4-9.Workspace IEQ and Control of attributes in the WorQ cognitive tests sample in day 3 (N=50): : Descriptive statistics

		Workspace IEQ	Control of workspace attributes
N	Valid	50	50
Mean		4.98	3.54
Median		5.00	3.50
Mode		6.00	2.00
Std. Deviation		1.39	1.95
Minimum		1.00	1.00

[26] A Kruskal-Wallis test compared IEQ and control values of open plan office workers who used desks assigned, and not assigned to them, respectively. The significance of the test is 0.041.

Maximum		7.00	7.00
Percentiles	25	4.00	2.00
	50	5.00	3.50
	75	6.00	5.00

The values seem to confirm the pattern observed in the sample overview: neither of the two distributions are normal, **and workspace IEQ values are generally higher than workspace control of attributes.**

As in the sample overview, day 3 values of **workspace IEQ and control of attributes are correlated** (Spearman's rho= 0.597, statistically significant at the 0.01 level). Correlations with choice of work space and time are also found to be statistically significant, as summarised below in table 4-10.

Table 4-10. Correlations between day 3 values of choice of work space and time, workspace IEQ and control of attributes in the cognitive tests sample (N=50)

			Choice of work space and time in day 3	Workspace IEQ in day 3	Workspace control in day 3
Spearman's rho	Choice of work space and time in day 3	Correlation Coefficient	1.000	0.693**	0.635**
		Sig. (1-tailed)	.	0.000	0.000
		N	50	50	50
	Workspace IEQ in day 3	Correlation Coefficient		1.000	0.597**
		Sig. (1-tailed)		.	0.000
		N		50	50
	Workspace control in day 3	Correlation Coefficient			1.000
		Sig. (1-tailed)			.
		N			50

**. Significant at the 0.01 level (1-tailed).

4.4.2. The mediating role of the workspace

The mediating role of the variables related to the workspace – IEQ; control over workspace attributes; premise; and type – has been explored. This was achieved by splitting the outcome data (cognitive learning) in groups that considered both the key predictor and the mediator variables. Different tests were used according to the nature of the mediators. As workspace IEQ and control of attributes variables are ordinal (ranging from 1 – 'Very dissatisfied' / 'No control' to 7 – 'Very satisfied' / 'Full control'), the Jonckheere-Terpstra test for ordered alternatives was used. Groups were created based on the ranks of the independent variable ('high' and 'low' choice) and the ranks of the mediators (figure 5-16). For the categorical variables workspace premise and type, Kruskal-Wallis tests were used. The results are summarised in table 4-11 and discussed below.

Figure 4-17. Choice or work space and time and workspace mediators: Diagram of ranks created for the analysis

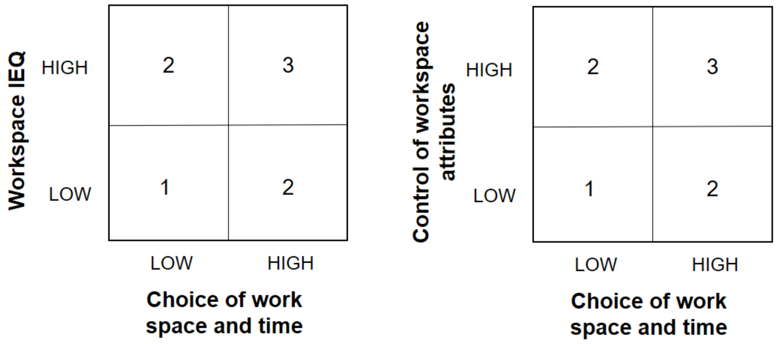


Table 4-11. Statistical test results: Choice of work space and time, the Workspace, and Cognitive learning in the WorQ cognitive tests sample (N=50)

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result: Retain or reject H0	Significance
4	Choice of work SPACE and TIME	Workspace Premise	Cognitive learning	Median Test	Retain	0.532
				Kruskal-Wallis	Retain	0.742
5	Choice of work SPACE and TIME	Workspace Type	Cognitive learning	Median Test	Retain	0.815
				Kruskal-Wallis	Retain	0.812
6	Choice of work SPACE and TIME	Workspace IEQ	Cognitive learning	Median Test	Retain	0.711
				Jonckheere-Terpstra	Retain	0.095
7	Choice of work SPACE and TIME	Control of workspace attributes	Cognitive learning	Median Test	Retain	0.479
				Jonckheere-Terpstra	Reject	0.037*

* Significant at the 0.05 level
Null hypotheses (H0) for independent samples tests:
Median Test H0: The medians of [dependent variable] are the same across categories of [independent and mediator variable].Mann-Whitney, Kruskal-Wallis and Jonckheere-Terpstra H0: The distributions of [dependent variable] are the same across categories of [independent and mediator variable].

No statistically significant associations were found when workspace premise and type were added as mediators of the choice - learning relationship (table 4-11, rows 4 and 5). The boxplot in figure B-11 (Appendix B) appears to confirm the findings discussed in section 4.3.3. '**Low choice' participants generally improved their cognitive tests scores more than 'high choice' participants, across workspace premises and types.**

The mediating role of the **workspace IEQ** makes no statistically significant difference on the choice - learning relationship table 4-11, row 6). However, figure 4-18 suggests the highest learning values are achieved by participants with *low choice and low IEQ*. Over 50% of these participants achieved values above the overall median, and the two highest values of 1047% and 718% also derive from the low choice, low IEQ group. **Control of workspace attributes** is found to have a statistically significant mediating role of the relationship between choice and learning (table 4-11, row 7). Participants with *low choice and low control* achieved the highest learning values (figure 4-19).

However, as shown previously in table 4-10, choice of work space and time, workspace IEQ and control of attributes are strongly correlated. This means that participants with low choice generally also perceive the quality of their workspace as less satisfactory ('low IEQ') and themselves having less control over its attributes ('low control'). This correlation may have a confounding effect on the choice / learning relationship.

Figure 4-18. Cognitive learning, Choice of work space and time and workspace IEQ in day 3 (N=50)

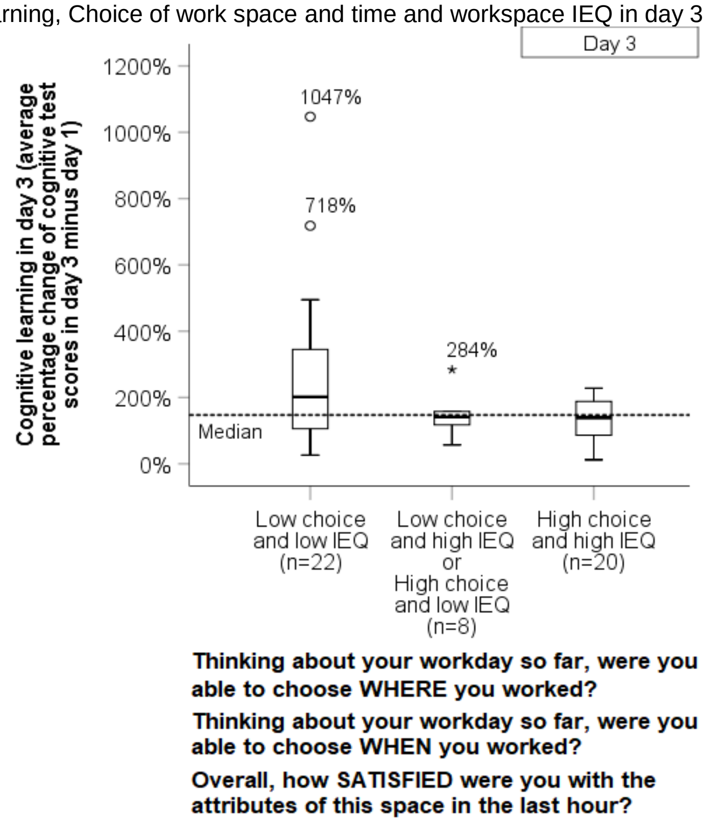
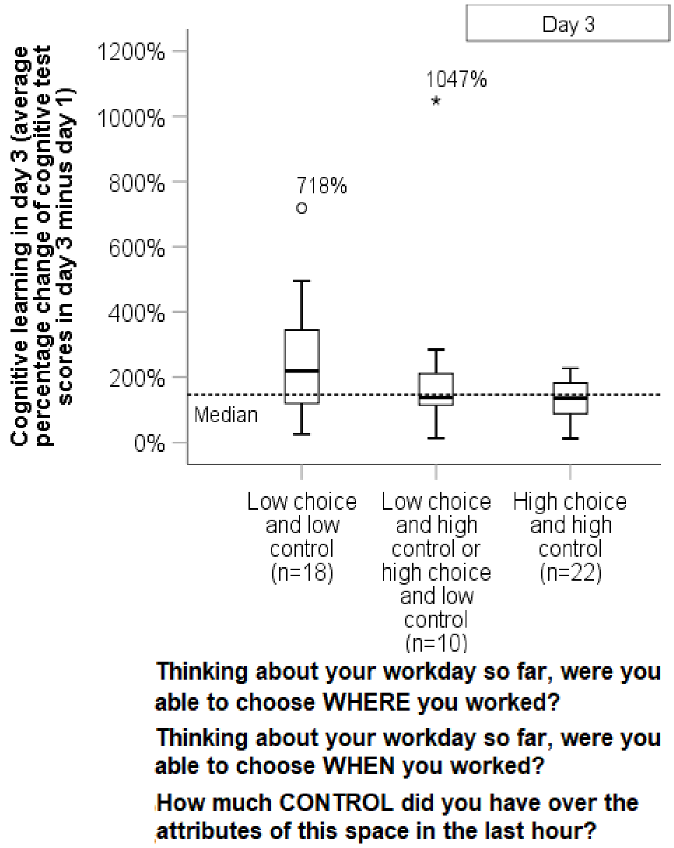


Figure 4-19. Cognitive learning, Choice of work space and time and control of workspace attributes in day 3 (N=50)



4.4.3. Specific workspace IEQ attributes (N=35)

A subset of 35 participants provided their perceptions of nine specific attributes ofthe IEQ of the workspace used in day 3: Temperature (TE); Air quality (AQ); Natural light (NL); Artificial light (AL); Noise (NO); Usability of furniture (UF); WiFi, IT, and work technologies (WT); Design and aesthetics (DA); and Privacy (PR). Descriptive statistics for the nine IEQ attributes are presented in table B-9 (Appendix B).

The 35 participants worked in their office buildings (n=30); at home (n=4), or in other premises (n=1). Office building workers worked in open plan offices, either at desks permanently assigned to them (n=19), or hot desks (n=10), or meeting spaces (n=1). Home workers used desks or tables in the living room, dining or kitchen areas (n=2), or enclosed home offices (n=2).

Nonparametric tests were used to assess the effects of the nine IEQ attributes on cognitive learning (table 4-12), because the distributions of the outcome variable and of most of the IEQ attributes[27] are non-normal. Tests found **all nine attributes to be negatively correlated with cognitive learning**. Three of the correlation coefficients were found to be **statistically significant** at 0.05 level (air quality: Spearman's rho: -0.383; artificial light: -0.299; WiFi, IT, and work technologies: -0.326) and one, significant at 0.01 level (natural light: -0.392). Correlations between the nine variables are presented in table B-10 (Appendix B).

Table 4-12. Correlations between cognitive learning and specific workspace IEQ attributes (N=35)

		TE	AQ	NL	AL	NO	UF	WT	DA	PR
Cognitive learning in day 3	Correlation Coefficient	-0.134	-0.383*	-0.392**	-0.299*	-0.155	-0.072	-0.326*	-0.130	-0.222
	Sig. (1-tailed)	0.221	0.012	0.010	0.040	0.187	0.341	0.028	0.229	0.100
	N	35	35	35	35	35	35	35	35	35

*. Correlation is significant at the 0.05 level (1-tailed).
**. Correlation is significant at the 0.01 level (1-tailed).

[27] According to one-sample Kolmogorov-Smirnov tests, eight of the nine IEQ variables are not normally distributed: Temperature; Natural light; Artificial light; Noise; Usability of furniture; WiFi, IT, and work technologies; Design and aesthetics; Privacy.

Acronyms: TE: Temperature; AQ: Air quality; NL: Natural light; AL: Artificial light; NO: Noise; UF: Usability of furniture; WT: WiFi, IT, and work technologies; DA: Design and aesthetics; PR: Privacy.

The average obtained from the nine workspace IEQ attributes in day 3 correlates positively and significantly with the workspace choice and quality variables measured daily:

- overall workspace IEQ in day 3: Spearman's rho coefficient 0.509, significant at the 0.01 level;
- choice of work space and time in day 3: 0.486, significant at the 0.01 level;

overall control of workspace attributes in day 3: 0.303, significant at the 0.05 level.

The average obtained from the nine workspace IEQ attributes on day 3 appears to correlate positively with the workspace choice and overall IEQ variables measured daily:

- overall workspace IEQ in day 3: Spearman's rho coefficient 0.509, significant at the 0.01 level;
- choice of work space and time in day 3: 0.486, significant at the 0.01 level;
- overall control of workspace attributes in day 3: 0.303, significant at the 0.05 level.

The correlation between IEQ (average) and the overall IEQ measured daily suggests that the latter may be an adequate summary measure of the quality of nine physical environment attributes commonly used to assess IEQ.

The strong correlations of IEQ (average) with choice and control indicate that participants who perceived having more choice of when and where they worked and more control over the attributes of the workspace tended to rate their workspace more favourably. **However, the association between choice, IEQ and control suggests IEQ and control may be confounders of the key relationship of interest.**

To explore the relationship between workspace IEQ and control of attributes, further statistical testing was conducted. This series of tests did not take choice of work space and time into account, but instead focused on the associations between the nine

IEQ attributes mediated by overall control of workspace attributes. Participants were divided into four ranked groups, and the medians and distributions of their cognitive learning results were compared: Low IEQ attribute and low control[28]; Low IEQ attribute and high control; High IEQ attribute and low control; High IEQ attribute and high control. As shown in table 4-13, five of the nine IEQ parameters mediated by control of attributes are associated to cognitive learning at a statistically significant level: Air quality, Artificial light, WiFi, IT, and work technologies, Design and aesthetics, and Privacy.

It is worth noting that all these associations are negative: participants in the 'low IEQ – low control' group tend to have higher cognitive learning values than the rest, judging by their distributions or medians. However, this could also be an effect of different sample sizes and characteristics of the four groups.

Table 4-13. Statistical test results: Specific IEQ attributes, overall Control of workspace attributes, and Cognitive learning (N=35)

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result	Significance
8-A	Temperature (TE)	Control of workspace attributes	Cognitive learning	Median test	Retain	0.643
				Jonckheere-Terpstra	Retain	0.104
8-B	Air quality (AQ)	Control of workspace attributes	Cognitive learning	Median test	Retain	0.312
				Jonckheere-Terpstra	Reject	0.046*
8-C	Natural light (NL)	Control of workspace attributes	Cognitive learning	Median test	Retain	0.057
				Jonckheere-Terpstra	Retain	0.050
8-D	Artificial light (AL)	Control of workspace attributes	Cognitive learning	Median test	Retain	0.299
				Jonckheere-Terpstra	Reject	0.044*
8-E	Noise (NO)	Control of workspace attributes	Cognitive learning	Median test	Retain	0.679
				Jonckheere-Terpstra	Retain	0.060
8-F	Usability of furniture (UF)	Control of workspace attributes	Cognitive learning	Median test	Retain	0.176
				Jonckheere-Terpstra	Retain	0.274
8-G	WiFi, IT, and work technologies (WT)	Control of workspace attributes	Cognitive learning	Median test	Retain	0.080
				Jonckheere-Terpstra	Reject	0.003*

[28] 'Low'=below group median, 'High'=at or above group median.

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result	Significance
8-H	Design and aesthetics (DA)	Control of workspace attributes	Cognitive learning	Median test	Reject	0.028*
				Jonckheere-Terpstra	Retain	0.264
8-I	Privacy (PR)	Control of workspace attributes	Cognitive learning	Median test	Reject	0.002*
				Jonckheere-Terpstra	Retain	0.054

Null hypotheses (H0) for independent samples tests:
Median Test: The medians of [dependent variable] are the same across categories of [independent and mediator variable]. Jonckheere-Terpstra: The distributions of [dependent variable] are the same across categories of [independent and mediator variable].

4.5.Demographic characteristics of the WorQ cognitive tests sample

The demographic characteristics of the cognitive tests sample are shown in figure 4-20 and described below.

- **Age and gender**

The cognitive tests sample includes **22 male participants (M), and 28 female participants (F)**. Their distribution across age groups is relatively uniform: there are 27 participants aged 20 – 39, and 23 participants aged 40 - 59. Most participants under 40 years old are female (10M, 17F); in the 40 – 59 age group, the distribution across genders is similar (12M, 11F).

- **Education**

In total, 35 participants (70%) completed graduate education (Levels 6 and higher), of which sixteen (32%) completed a Bachelors degree, eighteen (36%) completed a Masters and one has a doctoral degree (2%). The remaining fifteen participants completed high school (n=6 or 12%), or apprenticeships or diplomas (n=9 or 18%).

- **Skill levels**

Most participants in the cognitive sample are highly skilled (n=32 or 64%). In addition to this, fourteen participants (28%) are working in upper middle skill occupations, and four (8%) in lower middle skill roles.

All male participants are working in either upper middle or high skill occupations, while female participants are more evenly distributed across the skill level spectrum. This may be a result of uneven sample size – there are more female participants – or suggest a gender skill gap within the workforce.

- **Employment**

Most participants work full-time (n=44 or 88%), some are in part-time employment (n=5 or 10%) and one participant is self-employed (2%).

As suggested by the literature reviewed in Chapter 2, some demographic factors appear to be related to employment type. In the sample, participants who do not work full-time (n=6) tend to be in the older age group and female (n=5). The one self-employed participant is in the 40 – 59 age group and male.

- **Industry**

Participants are employed within the following industries: Professional, scientific and technical activities (n=17 or 34%); Real estate activities (n=13 or 26%); Financial and insurance (n=13 or 26%) or industries classified as 'Other' (n=7 or 14%). The latter includes 'Administrative & support service activities', 'Education', 'Charity' and 'Building industry'.

- **Job control**

The range of the job control variable is 6, with a minimum of 1 (n=1), maximum of 7 (n=8), mean of 5.02 and standard deviation of 1.44. The distribution of values is skewed towards the right. This indicates that participants across the sample tend to have a **moderate to high level of job control**. Financial and insurance professionals had a median value of 6 (compared to 5 for all the other industries) and the largest proportion of participants stating they have 'Full control' over their job.

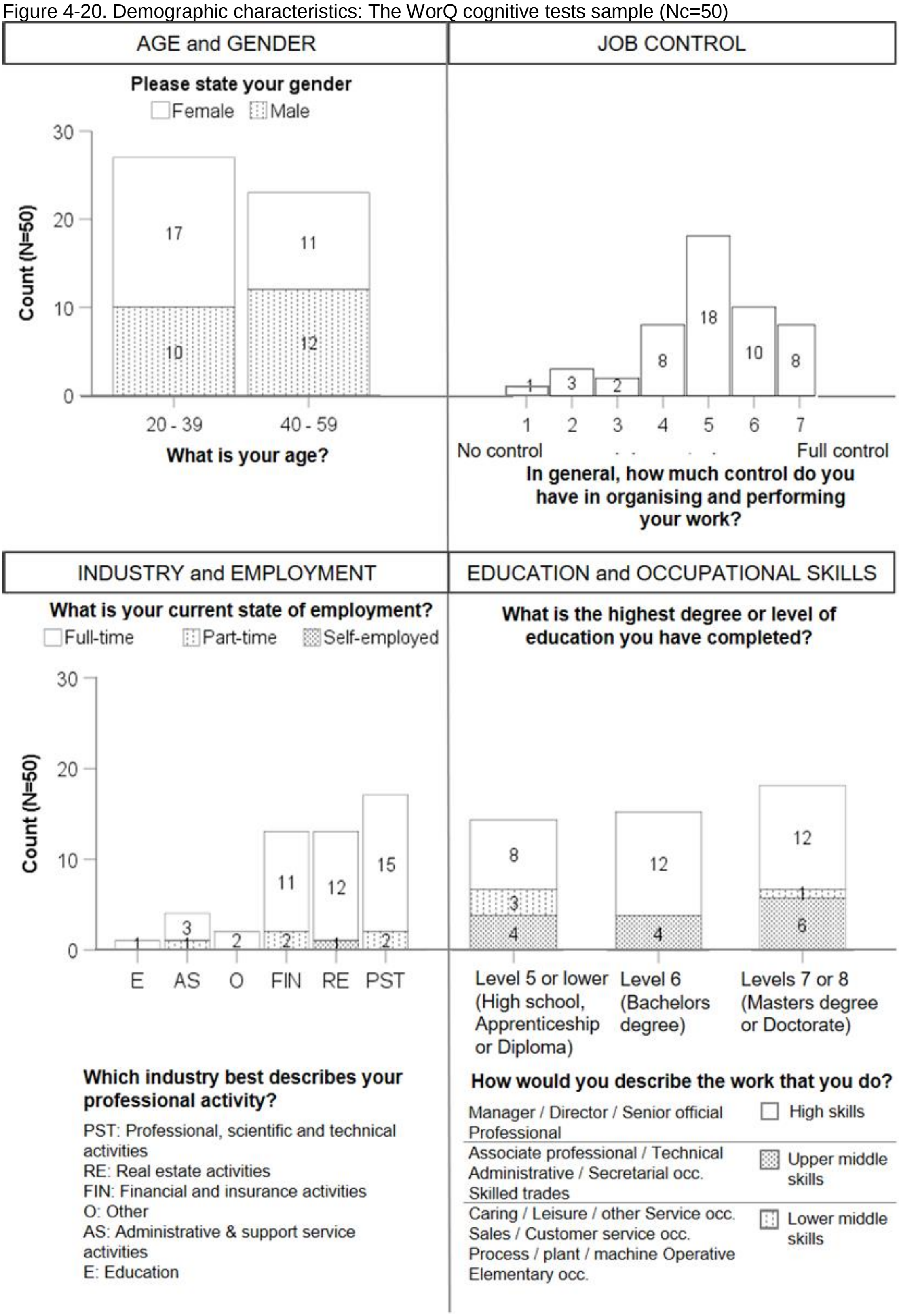
Gender and age analyses do not reveal major associations with job control. This may be an effect of the small and uneven sample sizes. Instead, **Job control**

appears to be associated with skill levels. Highly skilled participants tend to report higher levels of job control, compared to upper middle skill participants. The diversity of values obtained from lower middle skill participants – who have administrative or secretarial occupations - may not be meaningful due to the very small sample size (n=4).

- **Language:**

Of the 50 participants in the cognitive dataset, 45 had native proficiency of English language (90%), and five, non-native (10%). The five non-native English speakers are: Aged 20-39 (n=5); Male (n=2) and Female (n=3); Educated at Level 6 (n=1), Level 7 or 8 (n=4); working full-time (n=5) in the following industries: Professional, scientific and technical activities (n=4) and Education (n=1); Highly skilled (n=5). They have moderate to high job control levels: 3 (n=1), 4 (n=1), 5 (n=2), 7(n=1).

Figure 4-20. Demographic characteristics: The WorQ cognitive tests sample (Nc=50)



4.5.1. Choice, demographic mediators, and learning

As summarised in table 4-14 below, **no significant cognitive learning differences were found by considering the mediating effects of any of the demographic characteristics.**

Table 4-14. Statistical tests results: Choice of work space and time, Demographic characteristics

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result	Significance
9	Choice of work SPACE and TIME	Age	Cognitive learning	Median Test	Retain	0.528
				Kruskal-Wallis	Retain	0.473
10	Choice of work SPACE and TIME	Gender	Cognitive learning	Median Test	Retain	0.934
				Kruskal-Wallis	Retain	0.441
11	Choice of work SPACE and TIME	Employment	Cognitive learning	Median Test	Retain	0.473
				Kruskal-Wallis	Retain	0.387
12	Choice of work SPACE and TIME	Industry	Cognitive learning	Median Test	Retain	0.841
				Kruskal-Wallis	Retain	0.681
13	Choice of work SPACE and TIME	Education	Cognitive learning	Median Test	Retain	0.590
				Jonckheere-Terpstra	Retain	0.228
14	Choice of work SPACE and TIME	Occupational Skills	Cognitive learning	Median Test	Retain	0.813
				Jonckheere-Terpstra	Retain	0.635
15	Choice of work SPACE and TIME	Job control	Cognitive learning	Median Test	Retain	0.386
				Jonckheere-Terpstra	Retain	0.548

Null hypotheses (H0) for independent samples tests:
Median Test: The medians of [dependent variable] are the same across categories of [independent and mediator variable].Kruskal-Wallis and Jonckheere-Terpstra: The distributions of [dependent variable] are the same across categories of [independent and mediator variable].

4.6. Upper 25% and lower 25% cognitive learning (N=24)

To gain deeper understanding into what variables might be associated with particularly high or particularly low cognitive learning values, data from specific participants was analysed in more detail. Two groups were created to include participants whose cognitive learning values were in the upper and lower quartile ranges obtained in the sample:

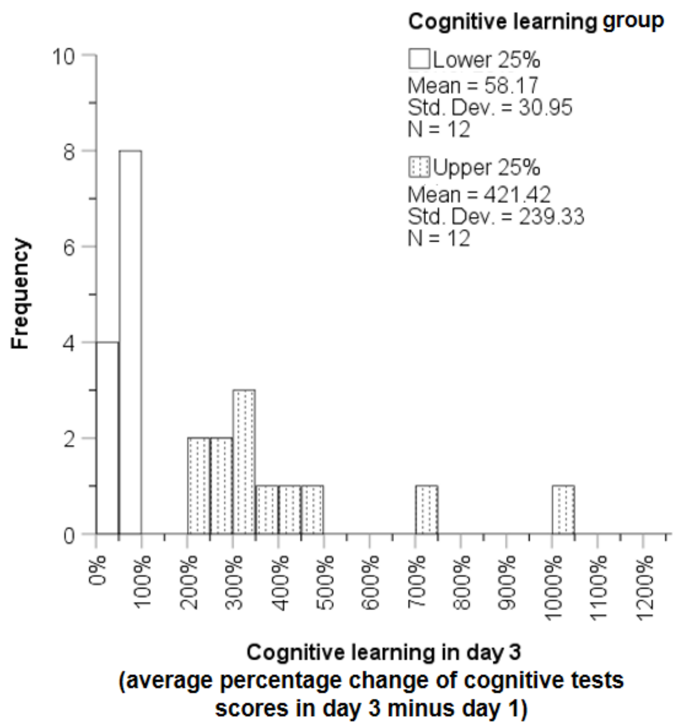
- Upper 25% cognitive learning group: participants who improved their cognitive tests scores by at least 221% → n=12%;
- Lower 25% cognitive learning group: participants who improved their

cognitive tests scores by 98% or less → n=12%.

4.6.1. Cognitive learning

Visual inspection of the histogram in figure 5-20 shows that the cognitive learning values of the lower 25% and upper 25% participants are distributed differently[29]. All the twelve values of the lower 25% group are concentrated below 100%, whereas the upper 25% values (n=12) are spread move evenly across the histogram bins. The different variation between the two groups is also shown by the St.Dev. values, considerably higher for the upper 25% group. Arguably, this suggests that after repeating the testing for three days, diminishing effects appear (a higher likelihood of obtaining lower improvement values). **Exceptionally high values such as 718% or 1047% are rare and may be due to chance.** Such values have been consistently marked as outliers by the statistical analysis software package.

Figure 4-21. Lower and upper 25% cognitive learning participants in day 3: Distribution of cognitive learning values (N=24)

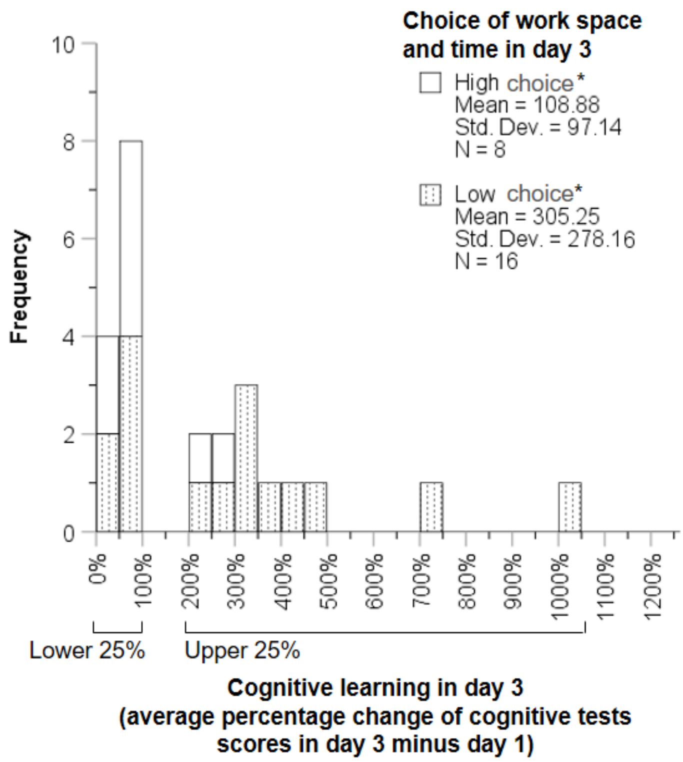


[29] This was also confirmed by a Mann-Whitney test (significance 0.000 at 0.05 level)

4.6.2. Choice of work space and time

The histogram in figure 4-22 supports the findings of the main body of analysis, specifically the apparent negative association between cognitive learning and choice of work space and time. Among participants with top 25% cognitive learning values, most had low choice: n=10 or 83%; among the low 25% learning participants, the proportion is even: six participants had high choice over when and where they worked, and six, low choice. The mean choice of work space and time value is higher for the lower 25% participants (3.95) than the upper 25% group (2.59). However, nonparametric statistical testing[30] did not reveal significant differences between the choice distributions of the two groups.

Figure 4-22. Choice of work space and time and cognitive learning: The upper and lower 25% cognitive learning group (N=24)



*'High choice': choice of work space and time values equal or higher than cognitive tests sample median in day 3 (4.00, N=50) and 'Low choice': values below sample median.

Figure 4-22 also highlights the predominance of low choice participants in *both*

[30] Mann-Whitney test, significance 0.069.

the lower and upper 25% cognitive learning groups. In this subset of 24 participants, the mean choice of work space and time is 3.27, and the median is 2.50, both lower than the values of the cognitive tests sample (3.81 and 4.00).

Thinking about the whole cognitive tests sample (N=50), this means that high choice participants are concentrated in the central areas of the cognitive learning distribution, i.e. between 100% and 200%. **Indeed, 73% of the participants in the second and third quartiles of the cognitive learning sample (n=19 of the total 26) had high choice of work space and time.**

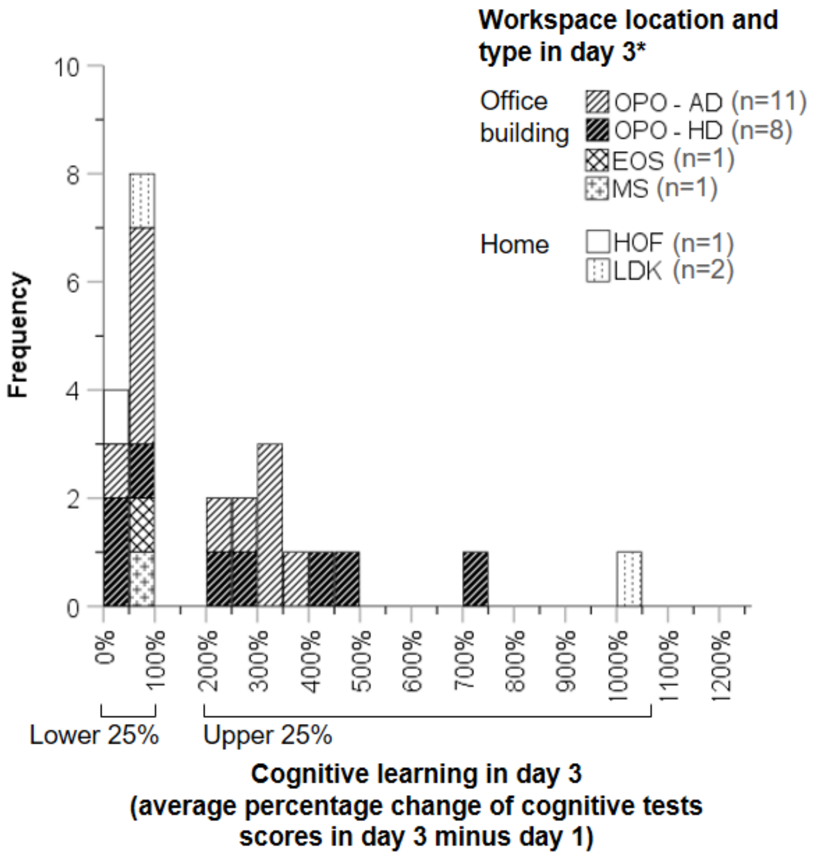
4.6.3. The role of the workspace

As shown in figure 4-23 below, most participants in the subset worked in the office building: n=21 of the total 24, or 88%. In the upper 25% cognitive learning tier, eleven of twelve participants worked in open plan offices located in office buildings, some at desks permanently assigned to them (n=6), or not assigned (n=5). However, the highest learning value obtained within the entire sample (1047%) was obtained by a participant who worked from home at a desk or table in the living, dining or kitchen area. In the lower 25% cognitive learning tier, there was more workspace type variety.

All five participants in the highest tier of cognitive learning (top 10% of the sample) have been categorised as having ‘low choice’ by comparison with the entire sample. However, it is perhaps worth mentioning that the workspace types used by them are associated with higher levels of choice. The highest value was achieved by a home worker. The second, third and fourth highest values (718%, 495%, and 420%) were achieved by participants working in open plan offices at desks not permanently assigned to them, and who are in general more able to choose where to work. However, no statistically significant effects are found.

The subgroup has comparable mean and median IEQ values to those obtained in the cognitive tests sample (4.67, and 5.00, compared to 4.98 and 5.00), and slightly lower control values (mean=3.29, median=3.00, compared to 3.54 and 3.50, respectively). As shown before in the main analysis, choice of work space and time are strongly correlated with workspace IEQ and control of attributes (Spearman's rho coefficients 0.591, and 0.721, respectively, both significant at the 0.01 level). As a result, differences in workspace IEQ and control of attributes between the lower 25% - upper 25% groups resemble those of choice of work space and time. The distributions of IEQ and Control values in the lower 25% cognitive learning group are significantly different from those in the upper 25% group[31]. Both mean and medians are higher for the lower 25% cognitive learning group.

Figure 4-23. Lower and upper 25% cognitive learning groups: Workspace premises and types (N=24)



OPO-AD: Open plan office - 8 or more people - Desk / workspace always assigned to me
OPO-HD: Open plan office - 8 or more people - Desk / workspace NOT assigned to me
EOS: Enclosed office - Shared with 1 to 7 colleagues
MS: Meeting space
LDK: Desk or table in the Living / Dining / Kitchen area
HOF: In a designated, enclosed workspace / Home office

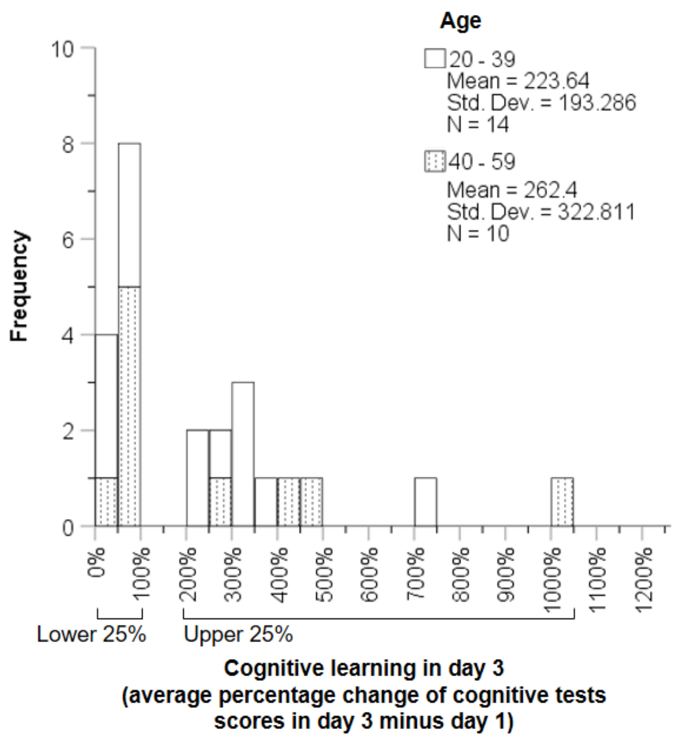
[31] Mann-Whitney tests for workspace IEQ and Control of attributes have significance coefficients of 0.02, and 0.06, respectively, both significant at 0.05 level.

4.6.4. Demographic characteristics

- **Age and Gender:**

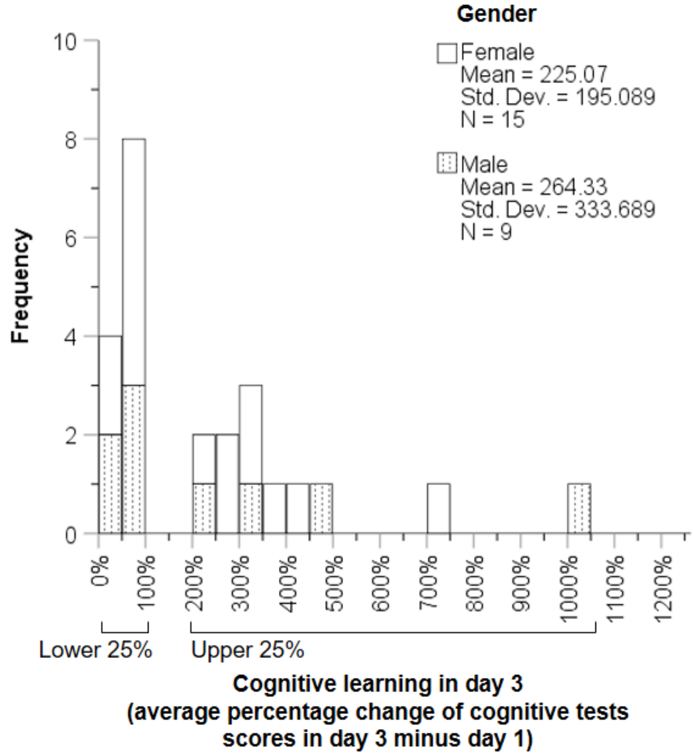
Figures 4-24 and 4-25 show the age and gender of the subgroup. There are more participants in the 20-39 age group than 40-59 (n=14; n=10). Despite the smaller sample size, the older age group has a higher mean cognitive learning value (262.4) compared to the 20-39 group (223.64), however most participants aged 40-59 are in the lower 25% learning group (six of a total of ten). The higher mean has resulted from the few very high learning values achieved by participants in this age group: 1047% (the highest value); 495% (third highest); and 420% (fourth highest).

Figure 4-24. Lower and upper 25% cognitive learning participants in day 3: Age (N=24)



In the sample, there are more female participants than male (n=15; n=9). While the mean cognitive learning value is higher for male participants (264.33, compared to 225.07), the proportion of male participants is lower in the upper 25% group: n=4 of 12, or 33%. As in the case of age, the higher mean is likely due to a few very high cognitive learning values (including 1047%).

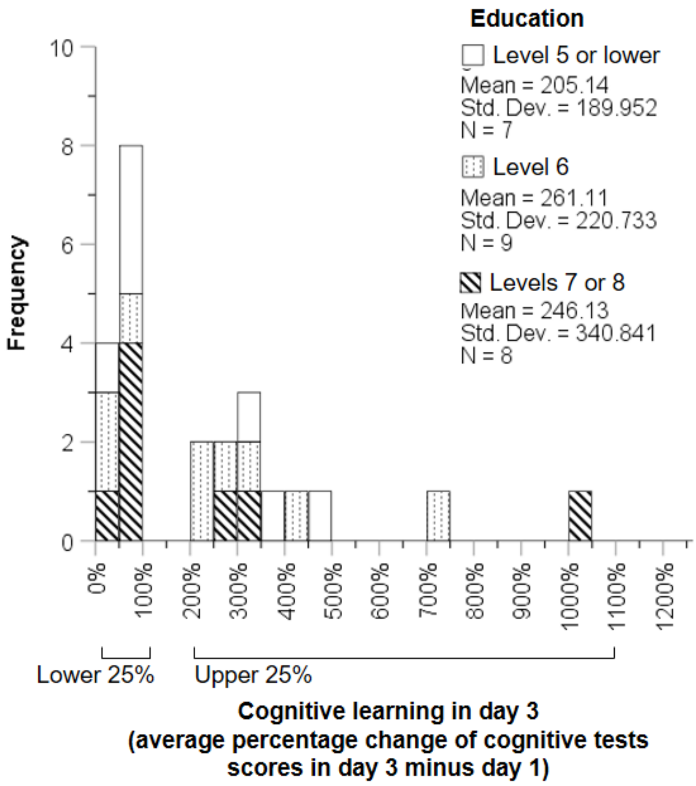
Figure 4-25. Lower and upper 25% cognitive learning participants in day 3: Gender (N=24)



- **Education:**

The distribution of cognitive learning results with participants' education marked reveals several associations that are perhaps unexpected (figure 5-25). These regard the presence of highly educated participants in the lower learning group, and of participants with basic education in the upper learning group. The highest value in the sample (1047%) belongs to a participant with the highest degree of qualifications measured in the study, Level 7 or 8 (Masters degree or Doctorate). However, several values in the upper 25th tier were achieved by participants with lower qualifications. The third highest learning value (495%), fifth highest value (386%), and eight highest value (314%) all belong to participants educated at basic level (Levels 5 or lower, Highschool, Apprenticeship or Diploma). In fact, the proportion of participants with basic and postgraduate education in the upper 25% learning group is equal (n=3 each, or 25%). The remaining 50% of the data belongs to participants with Level 6 qualifications (Bachelors degree). The opposite is also true: in the lower 25% group, there is a relatively high proportion on participants with postgraduate education (n=5). Given the highly educated characteristic of the overall sample (section 4.2.4.), the considerable number of high learning values achieved by Level 5 or lower participants represents an unexpected finding. However, section 4.6.5. suggests that lower baseline values might partially explain this effect.

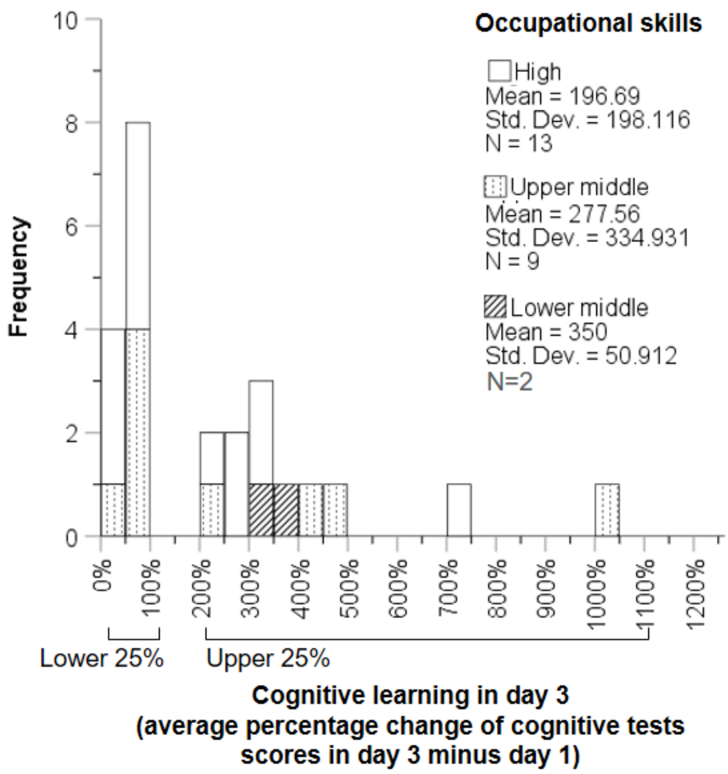
Figure 4-26. Lower and upper 25% cognitive learning participants in day 3: Education (N=24)



- **Occupational skills:**

Similar to the findings regarding participants' education, figure 4-27 suggests some unexpected associations between cognitive learning and occupational skills. Some of the highest learning values achieved in the sample were obtained from participants of upper middle or lower middle skills. Consequently, values obtained from highly skilled participants within the upper 25th group tend to be lower.

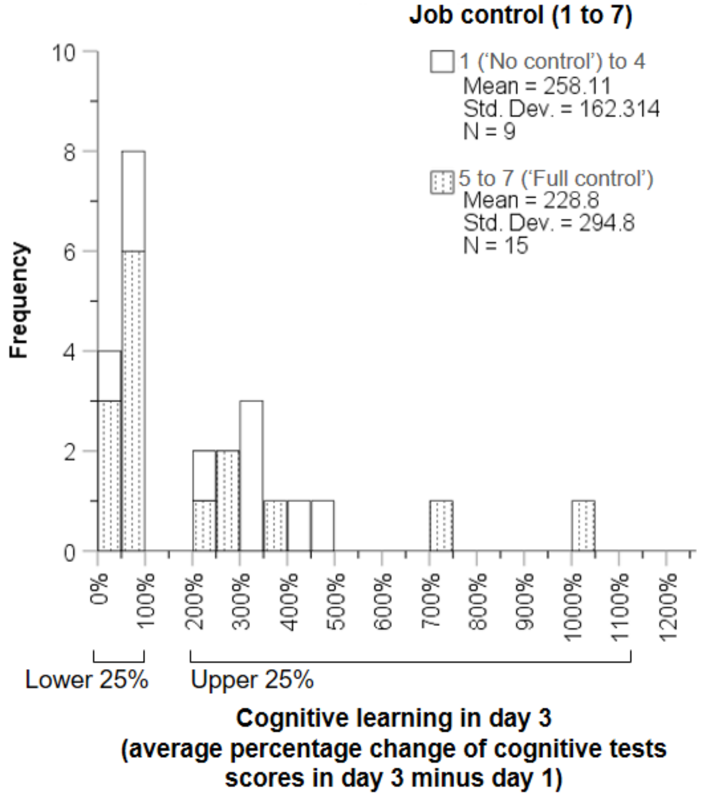
Figure 4-27. Lower and upper 25% cognitive learning participants in day 3: Occupational skills (N=24)



- **Job control**

Figure 4-28 shows the levels of general job control of participants with particularly high and low cognitive learning values. Perhaps surprising giving the literature on the benefits of job control, participants in the upper 25% learning group did not necessarily have significantly more job control than those in the lower 25% group. The proportion of participants with lower control is higher in the top 25% group than in the lower 25% group (n=3 of 12 in the lower 25% group; n=6 of 12 in the upper 25% group). As education, occupational skill levels, job control and choice of work space and time tend to be positively associated, this finding supports the trends already discussed.

Figure 4-28. Lower and upper 25% cognitive learning participants in day 3: Job control (N=24)



4.6.5. The relationship between absolute scores and cognitive learning

Given the unexpected negative associations found between choice and cognitive learning, the appropriateness of using a single *average* metric to quantify the learning outcome is worth discussing in more detail. Statistical analysis confirmed that cognitive learning in day 3 is associated with the percentage change of scores obtained at the BAB, TCR, TUN, and UNI tests.[32] However, the relationship between the absolute scores and the cognitive learning metric should perhaps be explored. This section of the analysis is based on observations drawn from the largest sample, the 98 participants who completed cognitive tests once daily for three days.

(A) ABSOLUTE SCORES AND PERCENTAGE CHANGE OF SCORES AT THE FOUR TESTS

[32] Spearman's rho correlation coefficients: BAB = 0.467; TCR = 0.418, TUN = 0.500, UNI = 0.477. All correlation coefficients are significant at the 0.01 level.

Nonparametric correlation tests were used to explore associations between the absolute scores obtained at the four tests for three days, and the percentage change of scores at each test in day 3. Significant Spearman's rho correlation coefficients were found between each of the pairs:

- BAB scores and BAB % change in day 3: 0.429;
- TCR scores and TCR % change in day 3: 0.246;
- TUN scores and TUN % change in day 3: 0.281;
- UNI scores and UNI % change in day 3: 0.290.

All four correlations are marked as significant at the 0.01 level. These associations can be expected given the fact that the **day 3 percentage change metric reflects the effect of repetition**, i.e. the third scores are usually higher than the first scores.

(B) ABSOLUTE SCORES AND COGNITIVE LEARNING

Statistical tests on the same sample (n=98) explored the relationship between the absolute scores obtained at each test over three days and the cognitive learning metric, calculated as an average of the four tests' percentage change values. This found that the **cognitive learning metric is negatively associated with the absolute scores**, with three of the four correlations being marked as statistically significant:

- Cognitive learning and TUN scores: Spearman's rho correlation coefficient = - 0.174, significant at the 0.01 level;
- Cognitive learning and TCR scores: -0.130, significant at the 0.05 level;
- Cognitive learning and BAB scores: - 0.114, significant at the 0.05 level;
- Cognitive learning and UNI scores: -0.074, not significant.

This generally means that **when the absolute values of the scores are low, cognitive learning is high, and vice versa**. A likely explanation involves the different 'weight' or 'power' of the three scores involved in calculating the metric, as shown below:

- The first score is considered the baseline. It is used twice in the calculation:
  - To measure learning in absolute terms: the difference between the third and first score;
  - To measure learning over time: the score difference is divided to the first score.
- The second score is omitted from the calculation;
- The third score is used to assess progress in absolute terms, as above.

The baseline score has the most significant ‘weight’ because the cognitive learning metric takes the effects of time into account. But the association between the baseline score and cognitive learning is **negative**. This is because numbers divided by small values result in larger answers than if divided by large values - e.g. 100 divided by 2 (answer: 50), is greater than 100 divided by 10 (answer: 10). **Consequently, low baseline scores are likely to lead to high learning values**. This was confirmed by the significant and negative correlations found between the first scores obtained at the tests and their respective day 3 percentage changes. All four correlation coefficients are significant at the 0.01 level: BAB %change (Spearman’s rho coefficient: -0.344), TCR %change (-0.314), TUN %change (-0.469), and UNI %change (-0.270).

However, as stated before in section 4.2.2. (A) (table 4-2), positive and statistically significant associations have been observed between the scores obtained at tests that examine the same cognitive skills, as shown below. This includes: TUN (working memory, sustained attention and visual recognition) and UNI (visual attention and visual recognition); TUN and TCR, and UNI and TCR (task shifting and response control). BAB (word fluency and working memory) correlates with all other three tests, especially with TUN.

Taking these findings into account simultaneously, it can be concluded that the **negative associations between absolute scores and the cognitive learning metric (average of four tests) can be explained by low first scores at one of the**

tests. Moreover, due to the significant 'weight' of the first score, *extremely low* baseline scores can lead to *extremely high* percentage change (average) values, as shown below.

(C) REVISION OF UPPER 25% AND LOWER 25% COGNITIVE LEARNING ANALYSIS

The baseline scores obtained by participants in the top 25% cognitive learning subsample (n=12) are listed in table 4-16 below. As suggested in the previous section, first scores and cognitive learning are negatively associated. **Eleven of the twelve participants in the upper 25% cognitive learning group had obtained at least one baseline score that were below the 25% or 10% threshold of the tests' ranges ('low' or 'extremely low').** Most participants, in fact, obtained two or more low or extremely low baseline scores out of a total of four. Two participants (002 and 023) had *all four* baseline scores below the respective 25% thresholds, one had three extremely low baseline scores (078), and four had two low baseline scores (100, 057, 054, 116).

Table 4-15. Baseline cognitive test scores obtained by participants in the upper 25% cognitive learning subset

Participant ID	Cognitive learning (day 3)	Baseline cognitive test scores (day 1)			
		BAB score 1	TCR score 1	TUN score 1	UNI score 1
078	1047%	750**	4100	70**	2050**
002	718%	2870*	800*	100**	2560*
100	495%	5520	2450	160**	2560*
033	420%	30230	3700	100**	5830
057	386%	7880	1950*	110**	5830
093	345%	9300	1550*	1110	3760*
054	322%	4470	2050	290**	3090*
065	314%	8860	3050	1150	4660
023	284%	1100**	200**	150*	1680**
032	272%	2600*	7150	860	5230
116	228%	8980	800*	620*	5230
063	226%	2430*	5250	1480	5230

Note: Values marked with an asterisk (*) represent scores below the 25% threshold of the four cognitive test ranges (BAB = 3083; TCR =2000; TUN=830; UNI=3960). Values marked with two asterisks (**) represent scores below the 10% threshold of the four cognitive test ranges (BAB = 1870; TCR =775; TUN=308; UNI=2560)

It may be worth highlighting the case of participant 078, who had the overall highest cognitive learning value of 1047%. Given that three of their four baseline scores in day 1 are extremely low (in the lower 10% of the respective score ranges), there is little surprise that scores obtained in days 2 and 3 increased, and that the cognitive learning value is so exceptionally high. The same reasoning applies for participant 002, who had the second highest cognitive learning value (718%) and all four baseline scores low or extremely low, and for most participants in the upper 25% cognitive learning sub set. Therefore, choice of work space and time may have had a smaller effect on cognitive learning, compared to that of the low baseline scores.

4.7. The cognitive learning metric: Reflections and revisions

The review of the current state of knowledge regarding the measurement of workspace productivity, revealed that traditional metrics based on counting work outputs are not applicable to knowledge work, which does not normally produce such outputs. Therefore, the first objective of the research was to create a more adequate metric. Performance on one or several cognitive tests was revealed as a proxy commonly used in evidence-based workplace productivity research (section 2.3). However, as explained in the Methodology section, this work aimed to obtain an overall cognitive learning metric that averaged performance on four tests. This was based on the intention of creating a comprehensive measure of learning.

At the time of developing the WorQ study methodology, no previous examples were available in which performance on several cognitive domains is averaged; instead, results on the different cognitive tests were presented and discussed separately. As the approach of the WorQ study is relatively novel, several questions can be examined:

1. Does the average measure of cognitive learning indicate any change over time?
2. How does the average measure of cognitive learning compare to its

four individual components, i.e. learning on the four different tests?

3. What is likely to have caused changes in the cognitive learning metric?

The response to the first question is yes. As shown in section 4.3.2. all participants in the sample improved their scores on the cognitive tests in day 3, compared to day 1. The range of cognitive learning values was situated between two positive values: 12% (Min) and 1,047% (Max), with a mean of 195. This increase occurred although on some of the tests, day 3 scores were lower than the baseline scores, as shown by the analysis of absolute scores (section 4.2.2.A and figure 4-6).

The learning values achieved on the four tests (as percentage change of scores in day 3 compared to day 1) correlated with each other, and the average cognitive learning metric. Tests that explored the same cognitive skills had the strongest correlations. This suggests that participants' innate inclination towards a particular cognitive domain determined their performance to be better at both tests that explored that domain, but not necessarily at the other ones. This is the main reason why the averaged metric was created – to balance individual differences between employees with different cognitive skills.

The third question has two likely answers.

Firstly, the improvement of scores at each test is likely due to repetition, i.e. more experience with the particular test and its instructions. Secondly, it was shown that the exceptionally high cognitive learning values obtained in day 3 were due to exceptionally low baseline values. Contrary to expectations, no other factors apart from choice of work time, which will be discussed separately – revealed any significant effects.

The second point can be discussed further. The equation used to determine cognitive learning, as presented in chapter 4, is:

$$\Delta Lt = \frac{St - Sb}{Sb}\ x\ 100$$

S = score

S_b = baseline score

t = time

This makes it very sensitive to baseline values. To illustrate the reasons why, the scores obtained by two participants at the same test can be compared.

Table 4-16. Comparison of two participants' results on the UNI test

Participant ID	UNI score 1	UNI score 2	UNI score 3	UNI cognitive learning in day 3
087	730	1070	2820	(2820 – 730)/730 x 100 = **286%**
066	14100	18840	17220	(17220 – 14100)/14100 x 100 = **22%**

Participant 087 achieved a considerably high value of improvement at the UNI test, 286%, while participant 066 achieved only a modest 22%. However, their starting points were very different. The baseline score of participant 087 is almost 20 times lower than that of participant 066, and the day 3 score is six time lower, yet according to the percentage increase metric, they learned significantly *more*. The metric assumes that the relationship between repetition and scores is monotonic, i.e. the difficulty of achieving a score increase from 730 to 2820 *is the same* as that from 14100 to 17220. However, this may not be the case.

4.7.1. Using day 2 as baseline

As shown above, the cognitive learning metric is strongly influenced by the first scores considered as baselines, with low first scores leading to high cognitive learning values. It is worth exploring whether this changes if the *second scores* are considered the baselines.

When the second day is considered as a baseline, the descriptive statistics of the cognitive learning variable change (table 4-17):

- The range is narrower, from -34% (Min) to 423% (Max);
- Mean, median, mode and percentile values become lower;
- A quarter of participants have negative scores, which means some of their second scores were higher than the third ones.

Table 4-17. Cognitive learning in day 3 calculated using Day 1 and Day 2 as baseline: Descriptive statistics

		Cognitive learning (Day 1 baseline)	Cognitive learning (Day 2 baseline)
N	Valid	50	50
	Missing	0	0
Mean		194.68	40.22
Median		145.50	29.50
Mode		80.00[a]	22.00[b]
Std. Deviation		178.28	67.65
Range		1035.00	457.00
Minimum		12.00	-34.00
Maximum		1047.00	423.00
Percentiles	25	98.00	-0.25
	50	220.75	29.50
	75	194.68	59.25

Multiple modes exist: 80. 141, and 147.
Multiple modes exist: 22 and 43.

Of the twelve participants with top 25% cognitive learning values, nine have obtained low or very low scores in the second day, i.e. below the 25% or 10% thresholds of the four tests (table 4-18). The observation made when analysing the cognitive learning results (with day 1 as baseline) therefore remains true: participants with the highest cognitive learning values have low or very low scores in the day considered as the baseline (day 2).

Table 4-18. Baseline cognitive test scores obtained in day 2 by participants in the upper 25% cognitive learning subgroup

ID	Cognitive learning (day 3)	Baseline cognitive test scores (day 2)				Notes
		BAB score 2	TCR score 2	TUN score 2	UNI score 2	
049	423%	11070	4200	70**	2890*	
002	147%	920**	4850	560*	9200	Day 1 baseline upper 25% group
115	115%	21120	550*	1520	9000	
023	108%	7290	350**	150**	2560*	Day 1 baseline upper 25% group
065	87%	20670	7350	1385	16640	Day 1 baseline upper 25% group
078	85%	2750*	7550	630*	8920	Day 1 baseline upper 25% group
148	83%	6830	8050	260**	5880	
016	78%		2750	870	930**	
033	77%	6190	6400	1300	17520	Day 1 baseline upper 25% group
058	73%	3620	1250**	1793	10500	
088	71%	7080	7800	964	10500	
066	66%	7990	1050*	2279	1070**	

Note: Values marked with an asterisk (*) represent scores below the 25% threshold of the four cognitive test ranges (BAB = 3083; TCR =2000; TUN=830; UNI=3960). Values marked with two asterisks (**) represent scores below the 10% threshold of the four cognitive test ranges.

Table 4-18 also shows that of the twelve participants with top 25% cognitive learning values, five are in also in the top 25% group created by using day 1 as a baseline. This suggests that their first *and* second scores were low or very low, which is true for all but one participant (ID 033).

For these twelve participants with high learning calculated using day 2 scores as the baseline, **no significant associations were found between cognitive learning in day 3 and any of the study predictors or mediators**. Choice of work space and time has no effect: six of the upper 25% cognitive learning group had high choice (above the day 3 choice median), and six had low choice (below the median).

4.7.2. Cognitive learning in days 4 and 5

To gain better understanding into the effects of repetition on cognitive learning, data are analysed from participants who completed the cognitive tests for four, and five days, respectively. The 50 participants in the cognitive tests sample include:

- 36 who completed the tests and workspace ratings for four days;
- 14 who completed the tests and workspace ratings for five days.

As shown before, the range and characteristics of the cognitive learning values were considerably different according to which day was used as a starting point, and low or very low baseline scores had an impact on the learning values. Most values that are low or very low were collected in day 1, and fewer, in day 2, **therefore the day 2 scores were used as a starting point.** Result show that:

- **Day 4 cognitive learning values** have a range of 252%, spread between the Min. value -27% and Max. 225%, and the following descriptive statistics:
  - Mean = 70%; Std. Dev = 66.52; Median = 52%, Mode

=109% (n=2).

- Percentiles: 25 = 18%; 50 = 52%; 75 = 109%.
- Cognitive learning results in day 5 (n=14):

In day 5, the following data were collected:

- **Day 5 cognitive learning values** have a range of 272%, spread between the Min. value -7% and Max. 279%, and the following descriptive statistics:
  - Mean = 109%; Std. Dev = 105; Median = 66%; all values are unique;
  - Percentiles: 25 = 26%; 50 = 66%; 75 = 229%.

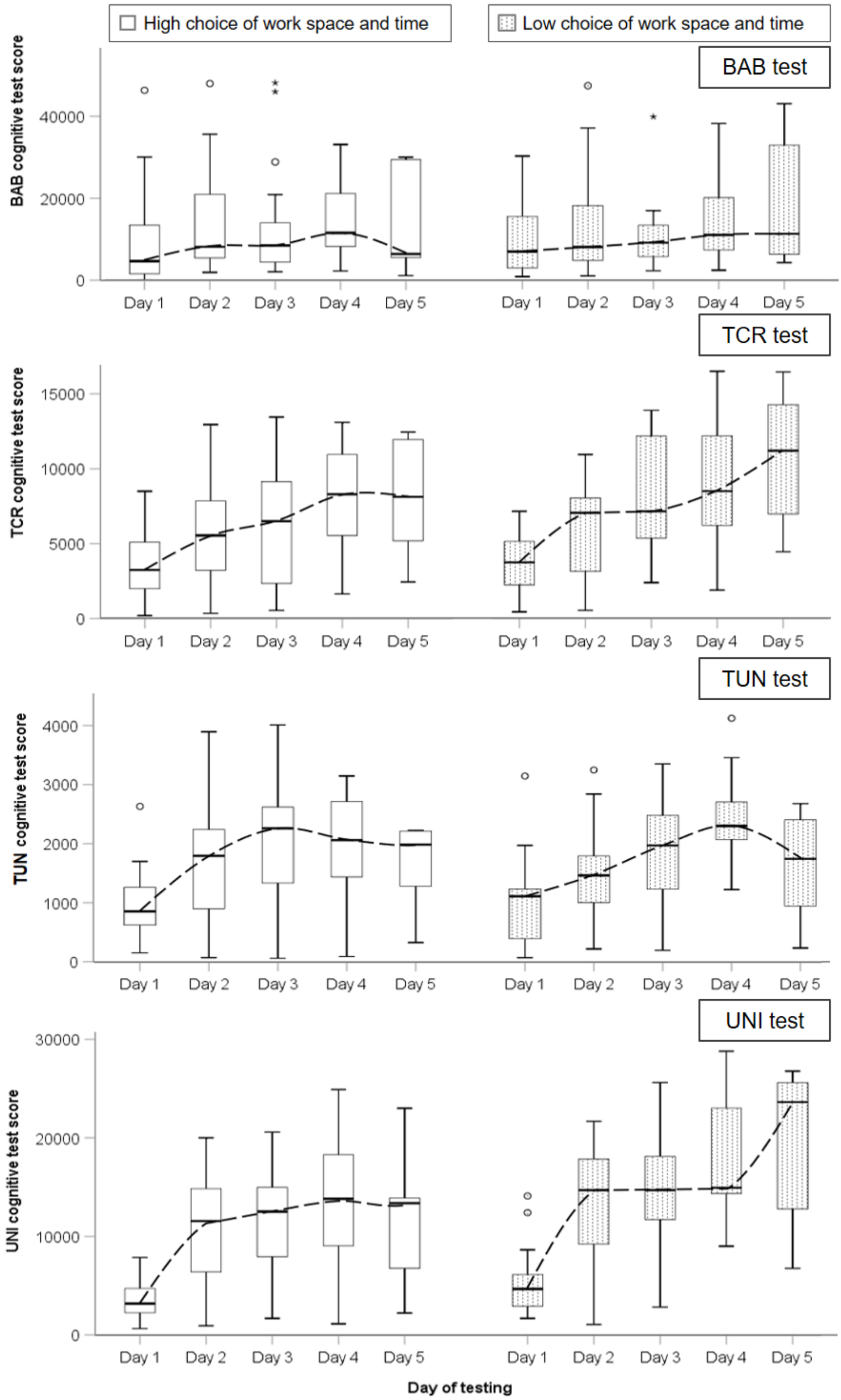
These results show that the increase of scores continues into days 4 and 5, but at a slower pace. Day 4 and 5 cognitive learning values are strongly and positively correlated (Spearman's rho = 0.974, significant at the 0.01 level). **This confirms that repetition of cognitive tests has a significant effect on the improvement of the cognitive learning values.**

However, apart from this, results found **no statistically significant relationships between choice of work space and time and cognitive learning in day 4 or 5.**

In summary, choice of work space and time did not reveal any significant associations with cognitive learning in days 3, 4 or 5, although repetition of the tests was strongly associated with the change of the cognitive learning values. At the same time, the scores obtained at the tests have been shown to have a strong impact on the cognitive learning calculated as average percentage change: low baseline scores lead to high cognitive learning values. It is therefore worth exploring how the cognitive test scores changed during the five testing days, and if this was related to participants' degree of choice of work space and time.

A possible effect can be observed when comparing the five-day learning curves of participants who had high choice of work space and those who had low choice (figure 4-29).

Figure 4-29. Median learning curves of participants with high and low choice of work space and time



In all four tests, high choice participants' median learning curves peaked a day earlier than those of low choice participants:

- High choice participants peak in day 4 for the BAB, TCR, and UNI tests, while 'low choice' participants peak in day 5;
- High choice participants peak in day 3 at the TUN test, while 'low' choice participants peak in day 4.

This difference was consistent for all four cognitive tests, which suggests that high choice participants may learn faster than low choice participants.

4.8. Choice and Wellbeing: The WorQ wellbeing sample (N_W=66)

This section presents how the third research objective was met:

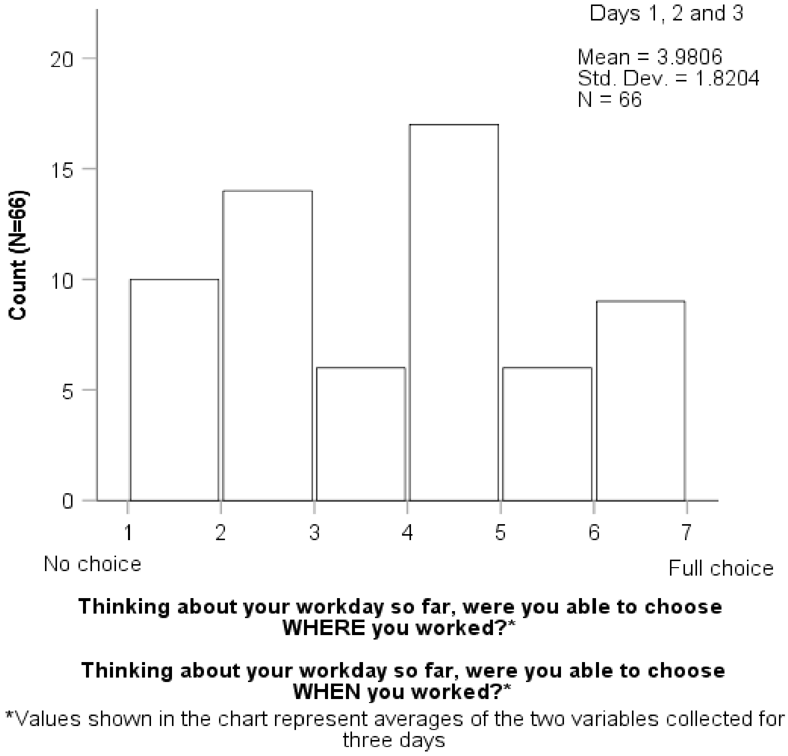
Objective 3	To assess the effect of choice of work space and time on wellbeing. **Key finding**: Choice of work space and time has a positive and significant effect on wellbeing.

4.8.1. Choice of work space and time: Average of first three days

As shown below in figure 4-30 and table 4-19, the distribution of choice of work space and time values (averaged for three days[33]) is non normal; this was also confirmed by the results of a nonparametric Kolmogorov-Smirnov statistical test.

[33] Due to the data collection process, fourteen participants mistakenly completed the wellbeing section in the second day instead of the third day. However, strong and significant correlations were found between choice of work space and time averages obtained for the first three, and first two days, respectively (Spearman's rho: 0.984, significant at the 0.01 level). Therefore, averages obtained from the first two days were used for the fourteen participants, and averages from the first three days, for the remaining participants.

Figure 4-30. Choice of work space and time in the WorQ Wellbeing sample: Distribution of values (N=66)



Key descriptive statistics show that the choice of work space and time levels of the wellbeing sample are slightly lower than those in the general sample (as described in section 4.2.3.), but *overall higher* than the cognitive sample:

- Mean: 3.98 in the wellbeing sample, compared to 4.25 (general sample, N=136) and 3.81 (cognitive tests sample, N=50);
- Median: 4.13 compared to 4.50 (general sample) and 4.00 (cognitive tests sample);
- Mode: 1.00, 4.83 and 6.00, compared to 7.00 (general sample) and 2.00 (cognitive tests sample);
- 25th percentile: 2.33, compared to 2.50 (general sample) and 2.00 (cognitive tests sample); 75th percentile: 5.50, compared to 6.00 (general sample) and 5.50 (cognitive tests sample).

Table 4-19. Choice of work space and time in the Wellbeing sample (N=66): Descriptive statistics

		Choice of work space and time (average of first three days)	Choice of work space (average of first three days)	Choice of work time (average of first thre days)
N	Valid	66	65	65
	Missing	0	1	1
Mean		3.98	4.08	3.97
Median		4.13	4.33	4.33
Mode		1.00	1.00	7.00
Std. Deviation		1.82	2.09	1.82
Range		6.00	6.00	6.00
Minimum		1.00	1.00	1.00
Maximum		7.00	7.00	7.00
Percentiles	25	2.33	2.17	2.59
	50	4.13	4.33	4.33
	75	5.50	6.00	5.33

As before, participants are divided into ‘Low’ and ‘High’ choice of work space and time categories based on the median of the sample:

- ‘Low choice’ participants (n=33) have choice of work space and time values (average of first three days) below the median 4.13;
- ‘High’ choice participants (n=33) have choice of work space and time values (average of first three days) above the median.

Consistent with the findings so far, choice of work space and choice of work time values are:

- Distributed differently:
    - Choice of work space ratings are somewhat polarised, with values concentrated towards the extremes; the distribution is not normal, according to statistical test results.
    - Choice of work time values are more evenly spread across the range of possible values; the distribution is normal according to statistical test results.
- Positively and significantly correlated (Spearman’s rho coefficient 0.683, significant at the 0.01 level).

4.8.2. Wellbeing

Wellbeing scores measured using the SWEMWBS scale are described below in figure 4-31 and tables 4-20 and 4-21. According to visual inspection of the histogram, and as confirmed by statistical analysis, (Kolmogorov-Smirnov test, significance 0.025), the wellbeing scores are not normally distributed.

Table 4-20. Wellbeing scores: Descriptive statistics (N=66)

N	Valid	66
Mean		22.07
Median		21.54
Mode		19.98[a]
Std. Deviation		2.66
Range		12.43
Minimum		16.88
Maximum		29.31
Percentiles	25	19.98
	50	21.54
	75	24.11

a. Multiple modes exist: 19.98, 20.73, and 25.03

Figure 4-31. Wellbeing scores: Distribution (N=66)

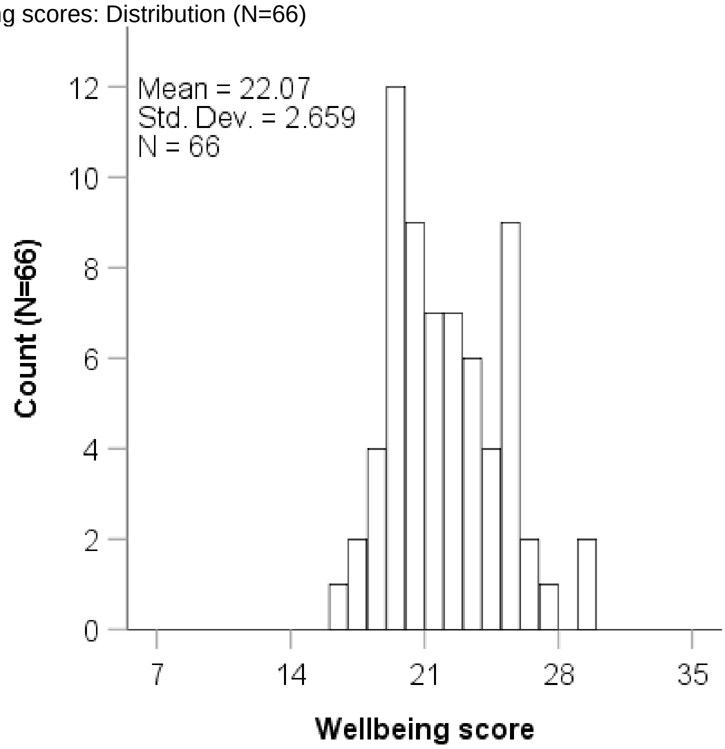


Table 4-21. Wellbeing scores: Frequencies of values (N=66)

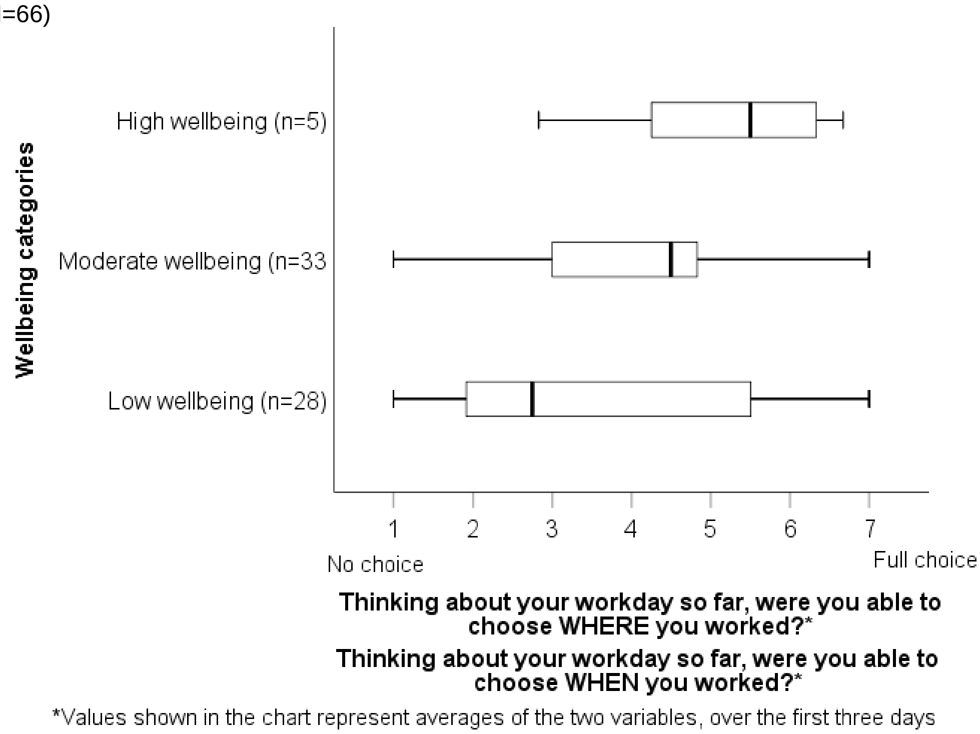
Wellbeing score		Frequency	Percent	Cumulative Percent
Value	16.88	1	1.5	1.5
	17.43	1	1.5	3.0
	17.98	1	1.5	4.5
	18.59	4	6.1	10.6
	19.25	3	4.5	15.2
	19.98	9	13.6	28.8
	20.73	9	13.6	42.4
	21.54	7	10.6	53.0
	22.35	7	10.6	63.6
	23.21	6	9.1	72.7
	24.11	4	6.1	78.8
	25.03	9	13.6	92.4
	26.02	2	3.0	95.5
	27.03	1	1.5	97.0
	29.31	2	3.0	100.0
	Total	66	100.0	

4.8.3. Choice and wellbeing

Initial statistical explorations of the choice of work space and time and wellbeing relationship used the absolute values of all variables without any clustering. This found no statistically significant correlations between choice of work space and time (averaged) and wellbeing (Spearman's *rho* 0.206) or choice of work space and wellbeing (0.129).

However, a potential association may be observed when grouping participants by their wellbeing level (according to the SWEMWBS guidelines) and exploring their average choice work space and time values for the first three days (figure 4-32 below). **The median choice values increase in parallel to wellbeing levels: they are lowest for low wellbeing participants and highest for high wellbeing participants.** This suggests participants with higher choice over when and where they work could have a higher sense of wellbeing (or vice versa). Yet, possibly due to the small size of the sample, there is an overlap between the choice values of participants across all three wellbeing categories.

Figure 4-32. Choice of work space and time (average of first three days) and Wellbeing level (N=66)



A more detailed examination of this relationship considers the *order of both variables*, by categorising participants into groups ordered according to their levels of wellbeing *and* choice of work space and time. Figure 4-33 shows the proportion of ‘High’ and ‘Low’ choice of work space and time participants within each of the three Wellbeing groups. An association can be observed:

- Among the 28 Low wellbeing participants, there are more participants with low choice of work space and time (n=18, or 64%) than high choice (n=10, 36%).
- In the Moderate wellbeing group (n=33), there are more participants with high choice (n=19, 58%) than low choice (n=14, 42%).
- Among the five High wellbeing participants, most have high choice (n=4 or 80%), and one (20%) has low choice.

Figure 4-33. 'High' and 'Low' Choice of work space and time across participants with Low, Moderate or High Wellbeing

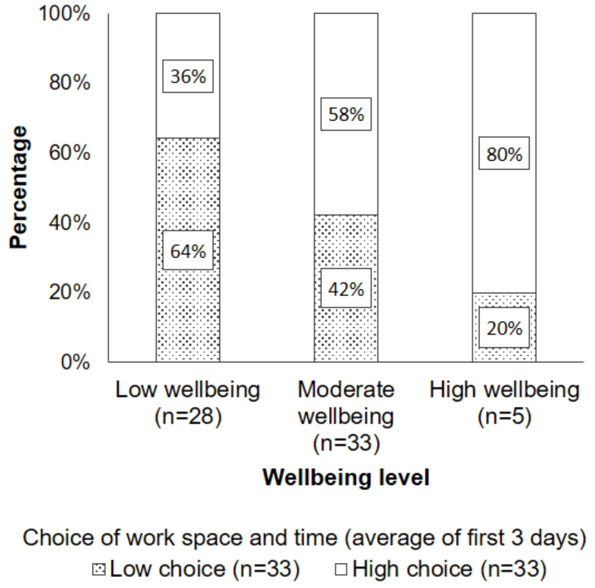


Table 4-22. Statistical test results: Choice of work space and time (average of first three days) and Wellbeing scores

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result	Significance
1	Choice of work SPACE and TIME	—-	Wellbeing	Median Test	Retain	0.324
				Jonckheere-Terpstra	Reject	0.031*
2	Choice of work SPACE	—-	Wellbeing	Median Test	Retain	0.390
				Jonckheere-Terpstra	Retain	0.147
3	Choice of work TIME	—-	Wellbeing	Median Test	Reject	0.352
				Jonckheere-Terpstra	Retain	0.085

*Statistically significant at 0.05 level.

Null hypotheses (H0) for independent samples tests:
Median Test H0: The medians of [dependent variable] are the same across categories of [independent and mediator variable].Mann-Whitney, Kruskal-Wallis and Jonckheere-Terpstra H0: The distributions of [dependent variable] are the same across categories of [independent and mediator variable].

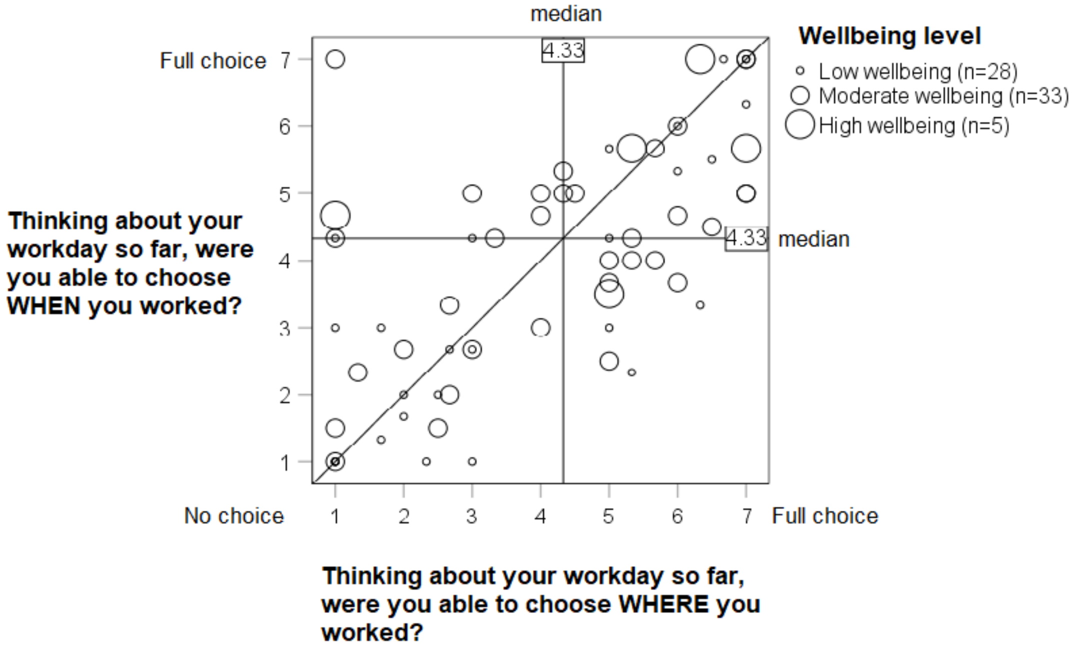
The association between choice of work space and time and wellbeing is statistically significant at the 0.05 level, according to a Jonckheere-Terpstra test (significance 0.031), as shown in table 4-22. However, when assessed independently, neither choice of work space nor choice of work time have been found to have statistically significant effects on wellbeing. This is particularly surprising, as a strong positive correlation was previously found between the choice of work time ratings and wellbeing scores. **This finding**

suggests that it may be the *combination* of the spatial and temporal aspects of choice that affects wellbeing, rather than just one of the two.

The nuances of this relationship can be further explored by considering the spatial and temporal aspects of choice in parallel, and how these might affect wellbeing. The scatter plot in figure 4-34 explores several relevant aspects. The position of the dots in the scatter plot represent the average choice of work space (X axis) and time (Y axis) in the first three days (n=52), or first two days (n=14). The size of the dots is proportional to their wellbeing, with smaller dots indicating low wellbeing, and larger dots, high wellbeing. The median values for choice of work space and time (both 4.33), are plotted as vertical and horizontal lines which divide the chart into four quadrants.

Firstly, as suggested by the diagonal line of the chart, **choice of work space and time (average of first three days) are positively and strongly correlated**: the Spearman's *rho* nonparametric correlation coefficient is 0.693, statistically significant at the 0.01 level.

Figure 4-34. Choice of work space, choice of work time (average of three days) and Wellbeing in the wellbeing sample(N=66)



Secondly, the chart confirms the findings presented before:

- Most participants with lower levels of workspace choice – i.e. situated below the medians - have low wellbeing;
- Most participants with higher levels of choice have moderate or high wellbeing.

Figure 4-34 also reveals that all five participants with high wellbeing have high levels of at least one of the two choice dimensions:

- Three participants are situated in the 'high choice' quadrant of the chart, above the medians of both choice of work space and time;
- One has low choice of work space -i.e. below the median - but high choice of work time;
- One participant has low choice of time of work, but high choice of space.

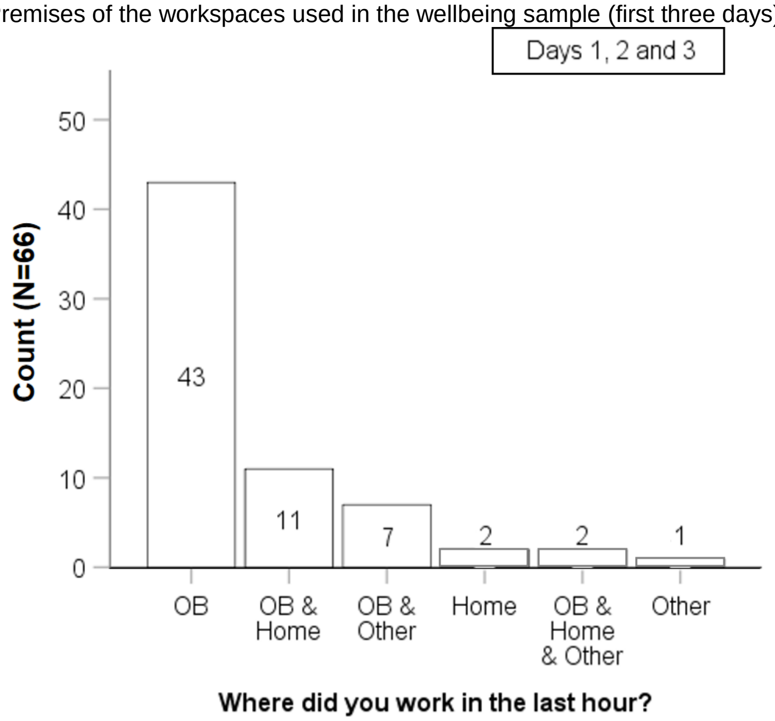
This could be due to natural variability within the sample, and the small sample size. However, this finding could also suggest that **spatial and temporal dimensions of workspace choice might work in tandem, with higher degrees of choice of time potentially compensating for low choice of space, and vice versa**.

4.8.4. Workspaces used in the wellbeing sample

(A) PREMISES AND TYPES

During the study period, participants in the WB sample worked solely in their office buildings (n=43, or 65% of the sample), solely at home (n=2, or 3%), or in other premises (n=1). Twenty participants (30%) used work settings situated: in their office building and homes (n=11 or 17%); in their office buildings and other premises (n=7, or 11%), or a combination of the three (n=2, or 3%). The most frequent settings classified as 'other' were different office buildings (figure 4-35).

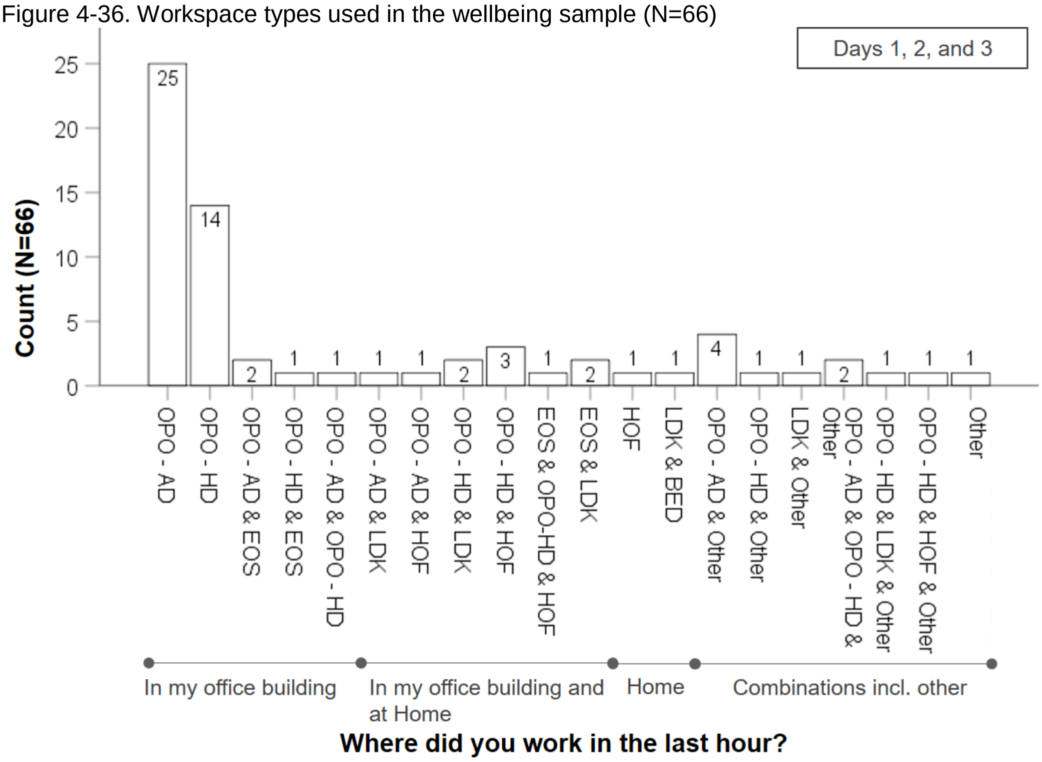
Figure 4-35. Premises of the workspaces used in the wellbeing sample (first three days)



*OB: In my office building

With regards to the type of workspaces used by participants during the observation period, figure 4-36 below shows a considerable variety of work settings situated in office buildings, homes, and other locations. 40 participants (61% of the sample) used a single workspace type during the three days. This includes 39 who worked in open plan offices, using desks permanently assigned to them (n=25), or hot desks (n=14), and one participant who worked exclusively from home, in a designated enclosed workspace or ‘home office’. The remaining 26 participants used two or three workspace types which included a variety of settings located in office buildings, their homes, and other premises.

Figure 4-36. Workspace types used in the wellbeing sample (N=66)



OPO-AD: Open plan office - 8 or more people - Desk / workspace always assigned to me
OPO-HD: Open plan office - 8 or more people - Desk / workspace NOT assigned to me
EOS: Enclosed office - Shared with 1 to 7 colleagues
LDK: Desk or table in the Living / Dining / Kitchen area
HOF: In a designated, enclosed workspace / Home office
BED: Desk or table in my bedroom

4.8.4.1. OVERALL WORKSPACE IEQ AND CONTROL OF ATTRIBUTES

As summarised in table 4-23 below, overall workspace IEQ and control of attributes describe slightly different patterns. The descriptive statistics of workspace IEQ are all higher than those of control. The IEQ ratings have a narrower range, spreading from 2.00 to 7.00, while the control ratings spread from 1.00 to 7.00; the mean, median, and mode values are higher for IEQ than for control. Based on the median values of the two distributions, participants are grouped into:

- ‘Low’ overall workspace IEQ (n=25, values below 5.00) and ‘High’ IEQ (n=41, values at or above 5.00);
- ‘Low’ control of workspace attributes (n=29, values below 3.33) and ‘High’ control (n=37, values at or above 3.33).

These findings suggest participants in the WorQ wellbeing sample **have generally rated satisfaction with their workspaces as being higher than the degree of control over their attributes**. According to statistical analysis, the two distributions are different, with IEQ being marked as non normal, while the control ratings may be normally distributed[34].

Table 4-23. Overall workspace IEQ and Control of workspace attributes: Descriptive statistics of WorQ Wellbeing sample (N=66)

		Workspace IEQ	Control of workspace attributes
N	Valid	66	66
Mean		5.02	3.67
Median		5.00	3.33
Mode		5.00	1.00[a]
Std. Deviation		1.26	1.80
Range		5.00	6.00
Minimum		2.00	1.00
Maximum		7.00	7.00
Percentiles	25	4.28	2.33
	50	5.00	3.33
	75	5.67	5.00

a. Multiple modes exist: 1.00, 2.33, and 4.00

As before, positive and strong correlations are found between:

- overall workspace IEQ and control of attributes (Spearman's rho correlation coefficient = 0.642, significant at the 0.01 level);
- choice of work space and time and:
  - overall workspace IEQ: Spearman's rho correlation coefficient = 0.642, significant at the 0.01 level)
  - control of workspace attributes: Spearman's rho correlation coefficient = 0.642, significant at the 0.01 level)

No significant correlations were found between wellbeing scores and overall workspace IEQ or control of attributes ratings.

[34] Nonparametric one-sample Kolmogorov-Smirnov tests significance: Workspace IEQ = 0.027 (significant at the 0.05 level); Control of workspace attributes = 0.200, not significant.

4.9. Choice, the workspace, and wellbeing

This section presents the results related to the fourth research objective:

Objective 4	To assess the mediating effect of the workspace on the relationship between choice of work space and time and wellbeing. **Key findings:** Control of workspace attributes is a significant mediator of the effect of choice on wellbeing.

The mediating effect of workspace premises was explored by splitting participants into the following categories, with no assumed rank between them:

- Low choice of work space and time and 1 workspace premise, n=23;
- High choice and 1 workspace premise, n=22;
- Low choice and 2 or 3 workspace premises, n=10;
- High choice and 2 or 3 workspace premises, n=11.

Given the considerable diversity of the types of work settings used by participants in the sample, the categories needed for the statistical analysis were based on the most common workspace types used, as follows:

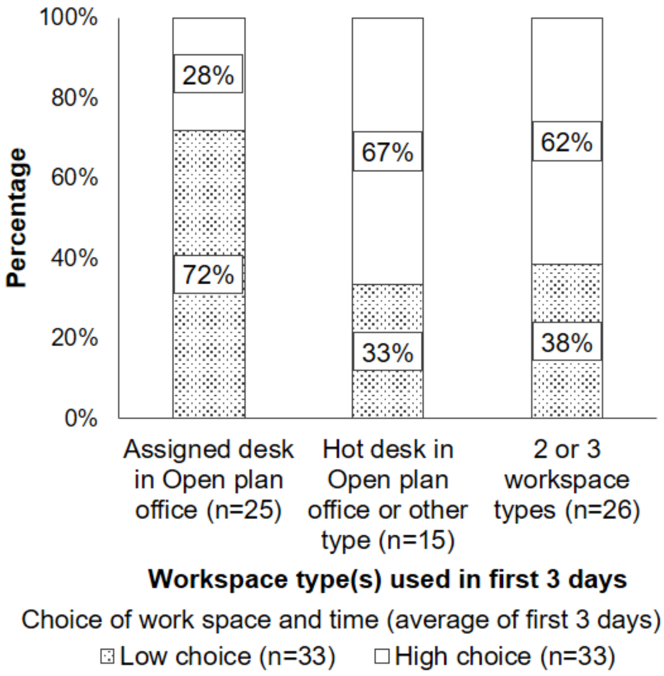
- Low choice of work space and time and 1 workspace type: Assigned desk in open plan office, n=18;
- High choice of work space and time and 1 workspace type: Assigned desk in open plan office, n=7;
- Low choice and 1 workspace type: Hot desk in open plan office or other type, n=5;
- High choice and 1 workspace type: Hot desk in open plan office or other type, n=10;
- Low choice and 2 or 3 workspace types, n=10;
- High choice and 2 or 3 workspace types, n=16.

This categorisation also highlights a potential association between choice of work space and workspace types. As shown in figure 4-37 below, the proportion of participants with low choice is considerably higher among those who used open plan office desks permanently assigned to them, than across the other two categories. Among the 25 participants who used assigned desks, over two thirds (72%, n=18) had low choice, and under a third (28%, n=7) had high choice of when and where they worked. Across the other two workspace type groups, the proportion of low to high choice participants is inverse: approximately two thirds have high choice, and one third, low choice:

- Hot desk in open plan offices: 67% have high choice (n=10), and 33% (n=5), low choice;
- Participants who used two or three different workspace types (and premises): 62% have high choice (n=16), and 38%, low choice (n=10).

The association between choice of work space and time and workspace type was found to be statistically significant at the 0.05 level[35].

Figure 4-37. Choice of work space and time across workspace type categories in the WorQ Wellbeing sample (N=66)



To explore the mediating effects of workspace IEQ and control,

[35] Nonparametric Median test result significance = 0.019. Kruskal-Wallis test result significance = 0.06.

participants were categorised into three *ranked* groups of similar sizes, as follows:

- Choice of work space and time (predictor) and overall workspace IEQ (mediator):
    1. Low choice and low IEQ: n= 19;
    2. Low choice and high IEQ, or high choice and low IEQ, n=20;
    3. High choice and high IEQ, n=27.
- Choice of work space and time (predictor) and control of workspace attributes (mediator):
    1. Low choice and low control: n=22;
    2. How choice and high control, or high choice and low control, n=18;
    3. High choice and high control, n=26.

Table 4-25 summarises the findings of the statistical analysis of the relationship between choice of work space and time and wellbeing, considering the workspace variables as mediators of the relationship.

Table 4-24. Statistical test results: Choice of work space and time, the Workspace, and Wellbeing in the WorQ Wellbeing sample (N=66)

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result: Retain or reject H0	Significance (asterisk if statistically significant)
4	Choice of work SPACE and TIME	Workspace Premise	Wellbeing	Median Test	Retain	0.500
				Kruskal-Wallis	Retain	0.331
5	Choice of work SPACE and TIME	Workspace Type	Wellbeing	Median Test	Retain	0.770
				Kruskal-Wallis	Retain	0.468
6	Choice of work SPACE and TIME	Workspace IEQ	Wellbeing	Median Test	Retain	0.149
				Jonckheere-Terpstra	Retain	0.177
7	Choice of work SPACE and TIME	Control of workspace attributes	Wellbeing	Median Test	Retain	0.124
				Jonckheere-Terpstra	Reject	0.020*

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result: Retain or reject H0	Significance (asterisk if statistically significant)

*Significant at the 0.05 level.
Null hypotheses (H0) for independent samples tests:
Median Test H0: The medians of [dependent variable] are the same across categories of [independent and mediator variable].Mann-Whitney, Kruskal-Wallis and Jonckheere-Terpstra H0: The distributions of [dependent variable] are the same across categories of [independent and mediator variable].

- No significant effects were found when workspace premises, type or IEQ were considered as mediators;
- Control of workspace attributes has a significant mediating role on the relationship between choice and wellbeing, (row 22 of the table).

As shown previously in section 5.4.3. (table 5-19), choice of work space and time has a statistically significant effect on wellbeing, i.e. participants with higher levels of choice tend to also have higher wellbeing scores. When control is considered as a mediator of this relationship, this effect increases. Participants with high choice of work space and time *and* high control over the attributes of their workspaces tend to have the highest wellbeing scores in the sample, while those with low choice and low control have the lowest wellbeing scores.

4.10. Demographic characteristics of the WorQ wellbeing sample

The demographic characteristics of the cognitive tests sample are shown in figure 4-38 and summarised below.

- **Age and gender**

The wellbeing sample includes **33 male participants (M), and 33 female participants (F)**. The sample includes more participants in the younger age group: there are 38 participants aged 20 – 39, and 28 participants aged 40 - 59. Most participants under 40 years old are female (16M, 22F); in contrast, in the 40 – 59 age group, there are more male participants (17M, 11F).

- **Education**

In total, 46 participants (70% of the sample) completed graduate and/or postgraduate education (Levels 6 and higher), of which nineteen (29%) completed a Bachelors degree, 25 (38%) completed a Masters and one has a doctoral degree (2%). The remaining nineteen participants completed high school (n=8 or 12%), or apprenticeships or diplomas (n=11 or 17%).

- **Skill levels**

Most participants in the cognitive sample are highly skilled (n=42 or 63%). In addition to this, sixteen participants (24%) are working in upper middle skill occupations, and eight (13%) in lower middle skill roles. 32 of the 33 male participants are working in either highly skilled occupations (n=23) or upper middle skill jobs (n=9), while the 33 female participants are more evenly distributed across the skill level spectrum (n=19 highly skilled, n=7 upper middle; n=7 lower middle). This could suggest a gender skill gap within the sample.

- **Employment**

Most participants work full-time (n=59 or 90%), some are in part-time employment (n=4 or 6%) or work in self-employed capacity (n=3 or 4%).

As suggested by the literature reviewed in chapter 2, some demographic factors may be related to employment type. In the sample, participants who do not work full-time (n=7) tend to be in the older age group (n=5). All four part-timers in the sample are female, and all three self-employed are male.

- **Industry**

Participants are employed within the following industries: Professional, scientific and technical activities (n=19 or 29%); Real estate activities (n=18 or 27%); Financial and insurance (n=17 or 26%), ‘Administrative & support service activities’ (n=10 or 15%) or industries classified as ‘Other’ (n=2 or 3%).

- **Job control**

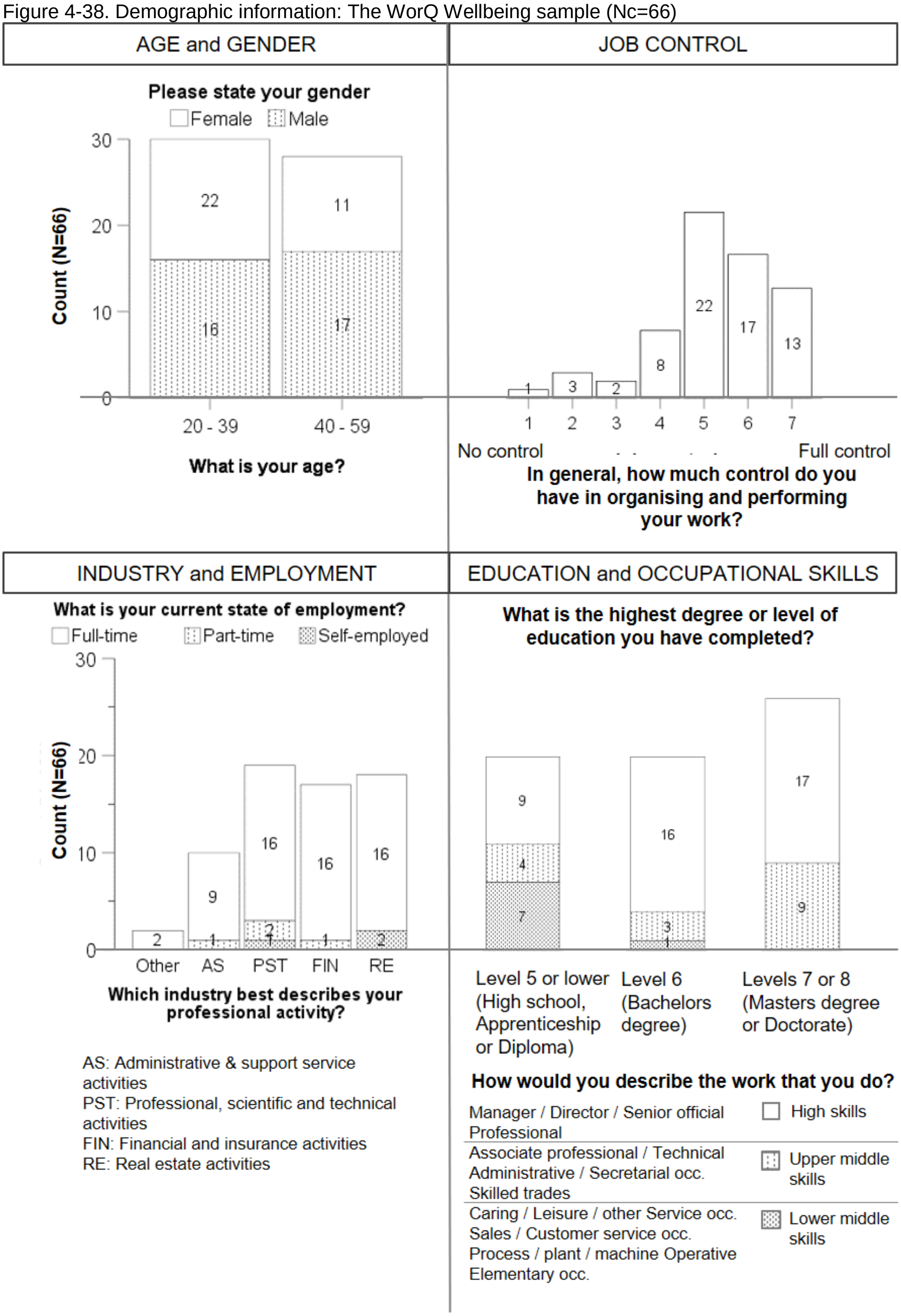
The range of the job control variable is 6, with a minimum of 1 (n=1), maximum of 7 (n=13), mean of 5.27 and standard deviation of 1.37. The distribution of values is skewed towards the right. This indicates that participants in the wellbeing sample tend to have a **relatively high level of job control**.

Job control appears to be associated with skill levels. Highly skilled participants tend to report higher levels of job control, compared to upper middle, and lower middle skill participants, respectively.

- **Language:**

Of the 66 participants in the cognitive dataset, 57 have native proficiency of English language (86%), and nine, non-native (14%). The nine non-native English speakers are younger: aged 20-39 (n=9); Male (n=5) and Female (n=4). They are also: Highly educated: Level 6 (n=2), Level 7 or 8 (n=7); working full-time (n=8) or part-time (n=1) across all industries: Professional, scientific and technical activities (n=5), Financial and insurance activities (n=1); Real estate activities (n=1); Administrative & support service activities (n=1) or other (n=1); mostly highly skilled (n=6) or with upper middle skill occupations (n=2); have moderate to high job control levels.

Figure 4-38. Demographic information: The WorQ Wellbeing sample (Nc=66)



4.10.1. Choice, demographic characteristics and wellbeing

Table 4-25 below shows the results of the statistical tests conducted to explore the mediating roles of the demographic characteristics of the sample in the relationship between choice of work space and time and wellbeing:

- No significant effects were found when the mediating role of the following variables was taken into account: Age, Gender, Employment, Education, Occupational skills, and Job control;
- Industry was found to have a strong mediating role (row 26).

Table 4-25. Statistical tests results: Choice of work space and time, Demographic characteristics and Wellbeing (NC=50)

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result	Significance
23	Choice of work SPACE and TIME	Age	Wellbeing	Median Test	Retain	0.210
				Kruskal-Wallis	Retain	0.269
24	Choice of work SPACE and TIME	Gender	Wellbeing	Median Test	Retain	0.105
				Kruskal-Wallis	Retain	0.224
25	Choice of work SPACE and TIME	Employment	Wellbeing	Median Test	Retain	0.300
				Kruskal-Wallis	Retain	0.510
26	Choice of work SPACE and TIME	Industry	Wellbeing	Median Test	Reject	0.037*
				Kruskal-Wallis	Reject	0.031*
27	Choice of work SPACE and TIME	Education	Wellbeing	Median Test	Retain	0.393
				Kruskal-Wallis	Retain	0.617
28	Choice of work SPACE and TIME	Occupational Skills	Wellbeing	Median Test	Retain	0.144
				Kruskal-Wallis	Retain	0.150
29	Choice of work SPACE and TIME	Job control	Wellbeing	Median Test	Retain	0.112
				Jonckheere-Terpstra	Retain	0.201

Null hypotheses (H0) for independent samples tests:
Median Test: The medians of [dependent variable] are the same across categories of [independent and mediator variable]. Kruskal-Wallis and Jonckheere-Terpstra: The distributions of [dependent variable] are the same across categories of [independent and mediator variable].

The mediating role of the Industry variable may be surprising. However, tests found that while in general, participants with higher choice of work space and time ratings had higher wellbeing scores - as stated before, choice has a significant effect - **this occurred across all industry categories**.

4.11. Workspace productivity: Supporters and detractors

This section presents how the fifth research objective was met:

Objective 5	To explore office workers' perception of what elements in the workspace support - and detract from – the ability to work productively. **Key finding:** Eleven themes were identified: Noise, Space and layout, People, WiFi, IT & work technologies, Distractions, Meetings, Usability of furniture, Temperature, Light, lighting and views, Privacy, Personal aspects.

This was achieved by exploring qualitative content collected during the WorQ study using thematic analysis with the aim of highlighting themes or patterns related to the perceived effects of workspaces on productivity.

4.11.1. Workspace categories

In total, 770 survey answers were collected from 130 participants: 385 were categorised in the 'Support' subset, and 385 in the 'Disrupt' subset. The number of surveys that contained meaningful content was smaller (372), as some surveys were left blank, and other contained generic, single word descriptions such as 'yes', 'no', 'fine' etc. Table 4-26 summarises the workspace location and type categories[36].

In summary, the qualitative data were obtained from participants who worked in the following premises:

- Home working: n=49 surveys (13% of total dataset) from 33 participants;
- Office building (OB): n=304 surveys (82%) from 125 participants;

[36] Participants who completed the questionnaire in more than one day were included in more than one case.

- Other: n=19 surveys (5%) from 17 participants.

Table 4-26.Workspace locations and types used by survey respondents, N=130

Workspace location	Workspace type	Surveys	Total
Home			49
	Bedroom	6	
	Home office	16	
	Living spaces (Living, dining or kitchen areas)	25	
	Outside	1	
Office building			304
	Assigned Desk	163	
	Corridor	1	
	Enclosed - Shared	13	
	Enclosed - Single	2	
	Hot Desk	119	
	Meeting space	5	
	Small, enclosed, quiet space	1	
Other			20
	Airport	1	
	Another office	11	
	Coffee shop	1	
	Meeting space	1	
	On a course	1	
	On site	2	
	On the train	2	
	Pilot plant	1	
	Total	372	372

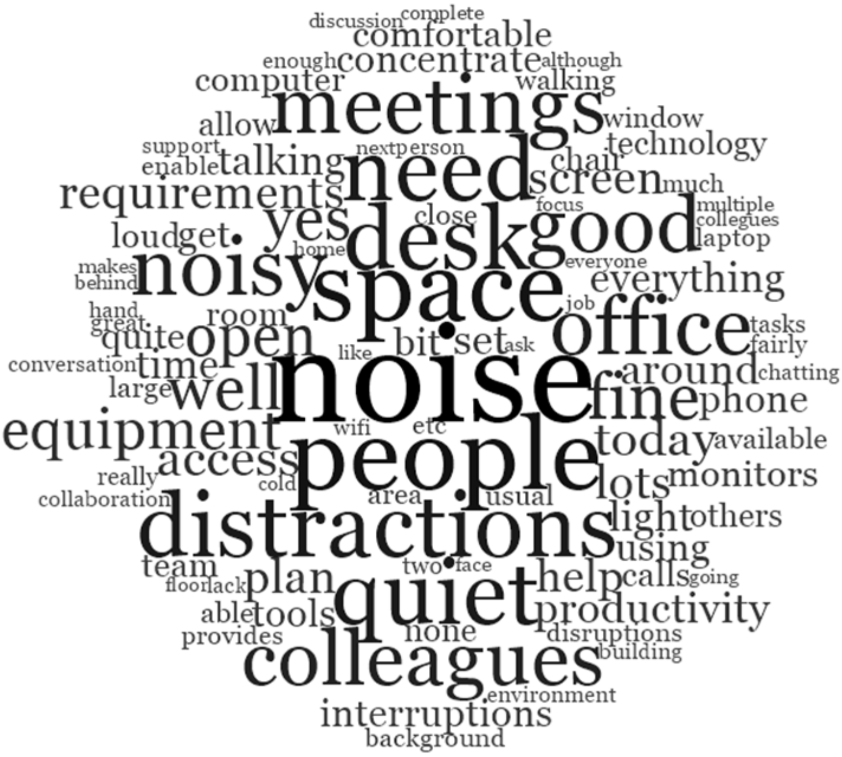
4.11.2. Subthemes and themes

Word frequency queries generated for the ‘Support’ and ‘Disrupt’ data (figures 4-39 and 4-40) revealed the key words used by the sample to describe the perceived effect of the workspace on productivity. Figure 4-39 shows which words were used most commonly to answer the question *‘How does your workspace support your ability to work productively?’*. Frequently used words – whose font is larger in the figure – include ‘quiet’ (used 38 times), ‘desk’ (32 mentions), or ‘equipment’ (19 mentions), and words whose meaning depends on context, such as ‘meetings’ or ‘need’. Figure 4-40 repeats the process for the second question “*Did any attributes of this space disrupt your ability to work productively?*”. ‘Noise’ and ‘noisy’ were mentioned most frequently (76 times in total), but many other common words such as ‘people’, ‘meetings’, or ‘distractions’ *had also been referred to as productivity supporters*.

Figure 4-39. Productivity supporters: Word cloud, all survey responses, N=130

Font size is proportional to frequency

Figure 4-40. Productivity detractors: Word cloud, all survey responses, N=130



Font size is proportional to frequency

Starting from these key words, and the specific context in which they were used, workspace productivity ‘supporters’ and ‘detractors’ subthemes were developed using thematic analysis. **40 subthemes were created across the two datasets.**

After the second and third readings of the text, the subthemes were revised and clustered within broader, more abstract themes. For example, subthemes such as ‘screen’, ‘printer’, ‘phone’ or similar elements were clustered under a broader theme called ‘WiFi, IT and work technologies’; subthemes ‘warm’ and ‘cold’ were clustered under the theme ‘Temperature’.

In total, eleven themes were identified:

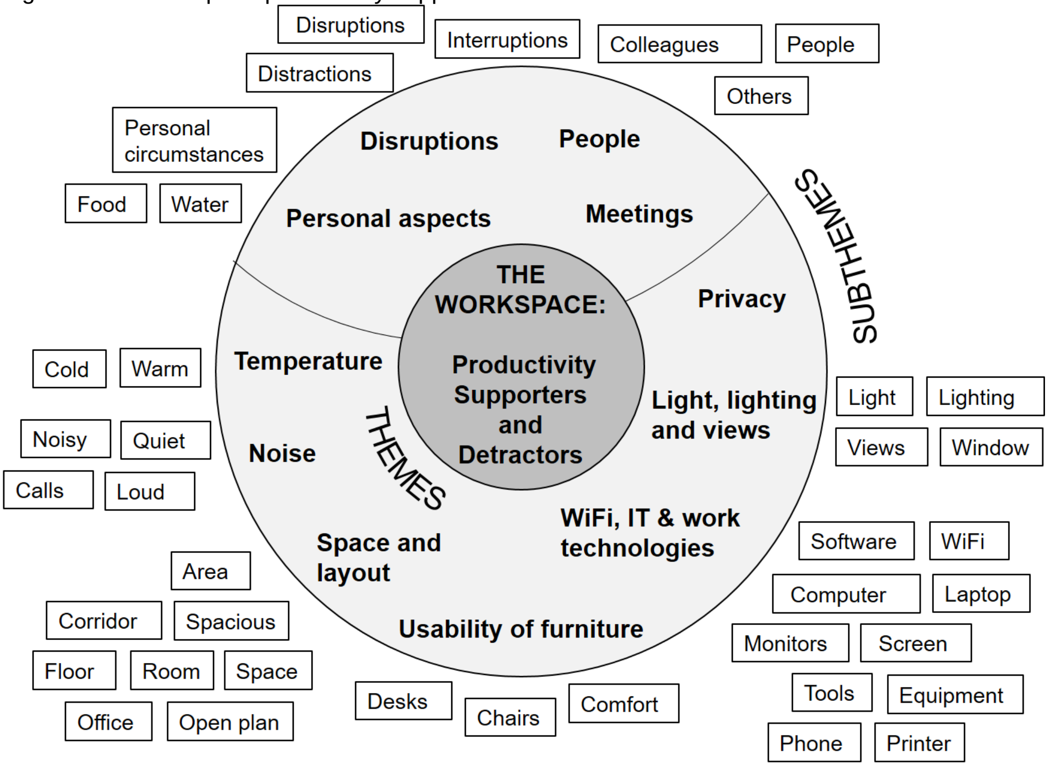
- *Noise
- Space and layout
- People
- *WiFi, IT & work technologies
- Distractions

- Meetings
- *Usability of furniture
- *Temperature
- *Light, lighting and views
- *Privacy
- Personal aspects

Six of these themes, marked with an asterisk in the list above, regard workspace features or parameters that were measured in the quantitative part of the research. These are *Noise; WiFi, IT and work technologies; Usability of furniture; Natural light; Artificial light* (clustered here together as *Light, lighting and views*); *Temperature and Privacy.* Moreover, many of the aspects included in the *Space and layout* theme are at least partially related to perceptions of workspace *Design and aesthetics*, which were also measured quantitatively.

Figure 4-41 shows the workspace productivity themes and subthemes identified in the WorQ study.

Figure 4-41. Workspace productivity supporters and detractors: Themes and subthemes



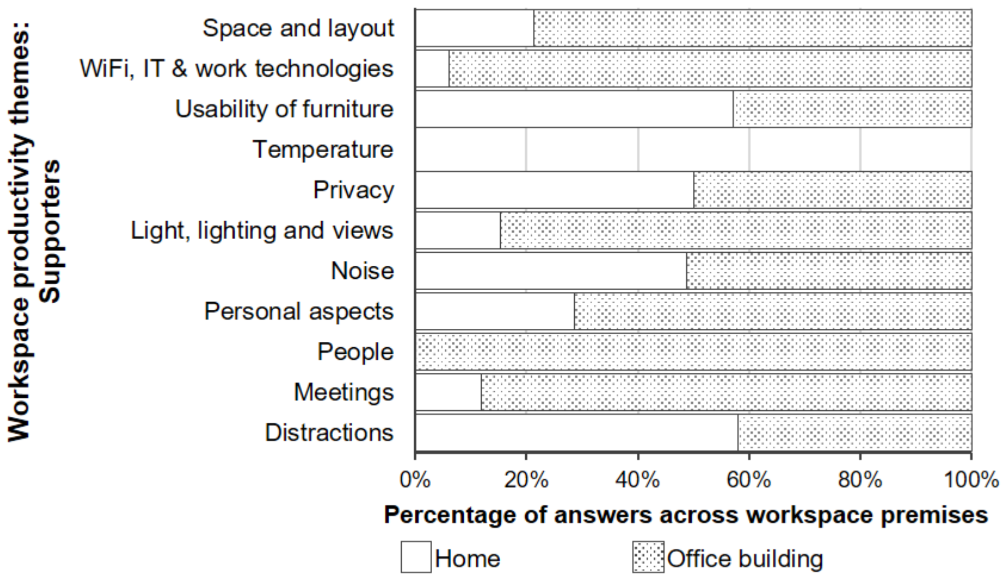
It is perhaps worth mentioning that of the eleven themes, five are directly related to the physical dimensions of the workspace. While the remaining aspects implicate the environment as a setting, they primarily refer to psychosocial dimensions of the work life - *People, Distractions, Meetings*, and *Personal aspects* – or aspects related to work itself, *WiFi, IT & work technologies.*

4.11.3. Workspace themes: Productivity supporters

The themes created for the dataset were explored using matrix coding processes, which search for mentions of the themes or subthemes in the data obtained from different types of workspace users. This revealed specific aspects related to workspace productivity across the different types of workspaces or settings.

Figure 4-42 shows the key themes associated with having beneficial productivity effects by participants working from Home and in the Office building; no themes could be identified for respondents working in Other spaces. The results are shown in percentages of the total number of times the theme was mentioned, to indicate similarities and differences between the two groups.

Figure 4-42. Workspace productivity supporters: Themes across workspace premises

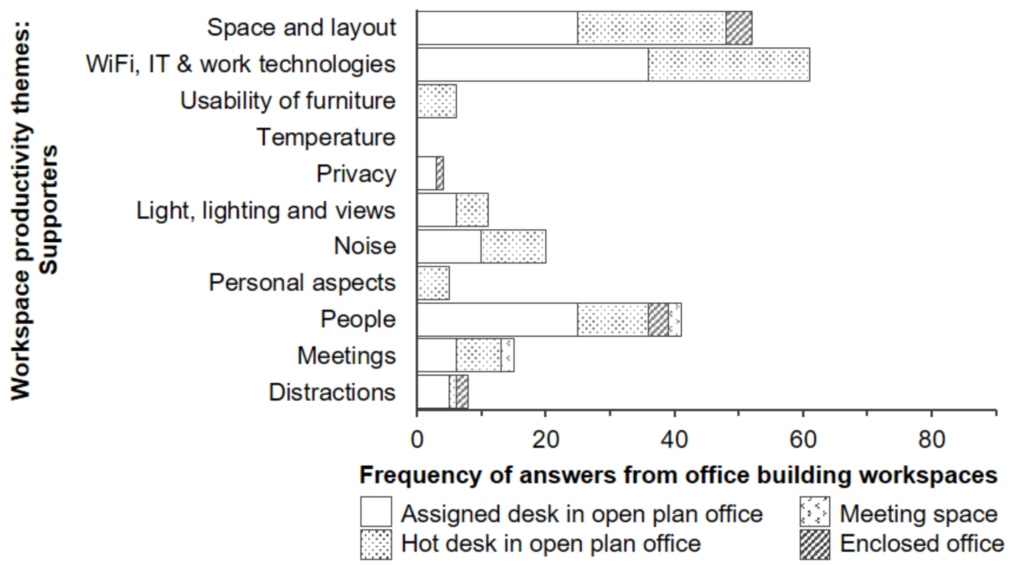


The figure shows that most themes were related to both categories of workers, one was only mentioned by office workers, and one by neither. Both office and home workers indicated that WiFi, IT and work technologies support their ability to work productively, but office workers appeared to value it above all other features: of all answers that referred to this theme, 94 percent came from office workers. Likewise, the *Usability of furniture* and working in an environment free from *Distractions* and *Noise* was mentioned by home and office workers, but for the former, these themes were most prominent. Specific examples are discussed below.

(A) OFFICE BUILDING WORKSPACES

As described earlier, most respondents in the sample worked in the office building. The most frequent workspace setting was the open plan office, with numerous responses obtained from workers using permanently assigned desks (163 surveys) and hot desks (119). Figure 4-43 shows the different proportions in which the different workspace themes were considered conducive to productivity by different workspace users.

Figure 4-43. Productivity supporters: Office building workspaces



Most respondents across all types of office building workspaces referred to aspects regarding *WiFi, IT and work technologies.* Open plan office workers with assigned desks thought that "*this space … support[ed] my work by having access to PC with dual monitors, access to the network, email and online communication*", while hot desk users commonly mentioned having access to technology such as 'wide computer screens', 'telephone and headset' etc. One even considered this to be the most important aspect of productivity:

"*All technology working, technology is 70% of my work*".

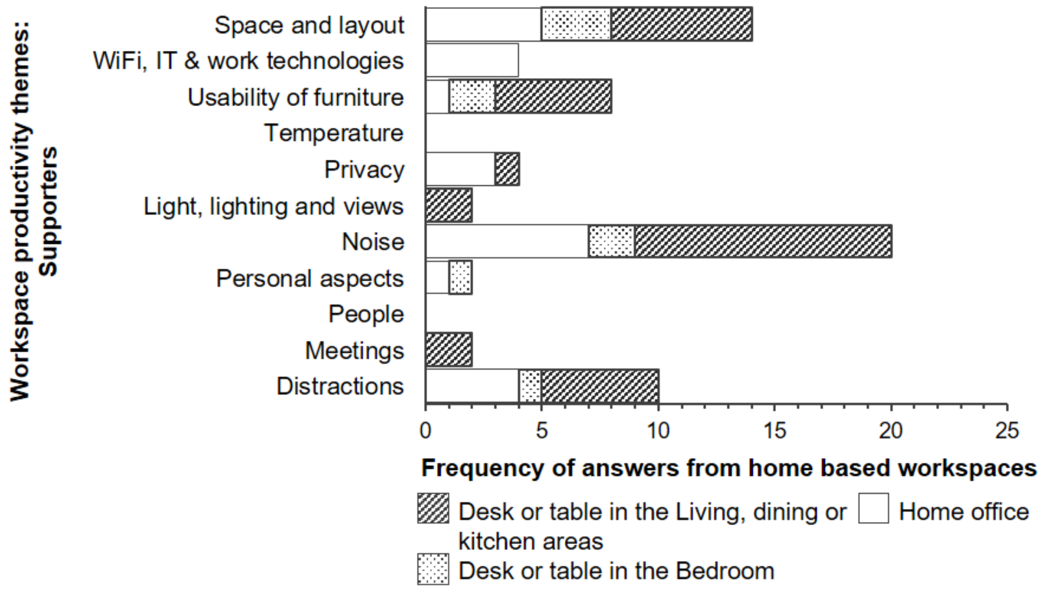
Aspects regarding *Space and layout, Noise* – i.e. the absence of - and *Light, Lighting or views* were mentioned by both open plan worker types, but more prominently by those using hot desks, as shown by the almost equal number of responses from both categories. Examples include listing aspects such as "spacious office", "quiet" spaces, "good daylight" or "wide windows" as elements that support productivity. It is perhaps unsurprising that most references to the quiet in hot desking areas underline its exceptional nature: "quieter today" or "For once, it was pretty quiet"; otherwise, it "can be a noisy area". Some aspects regarding the *Usability of furniture* such as "comfortable chair" or desk size are only mentioned by hot desk users. Other issues classified as *Personal aspects,* related to food or refreshments are also solely referred to by participants with no permanent desks.

Proximity to *People* was generally regarded as beneficial by all types of office workers, particularly those using assigned desks in open plan offices, because *"[having] colleagues in close proximity enables team working across multiple projects".* Similarly, participants working in meeting spaces considered "*working with the people I needed to*" productive.

(B) HOME BASED WORKSPACES

The absence of *Noise* and *Distractions* were amongst the most common aspects regarded as conducive to productivity when working from home, as shown in figure 4-44.

Figure 4-44. Productivity supporters: Home based workspaces



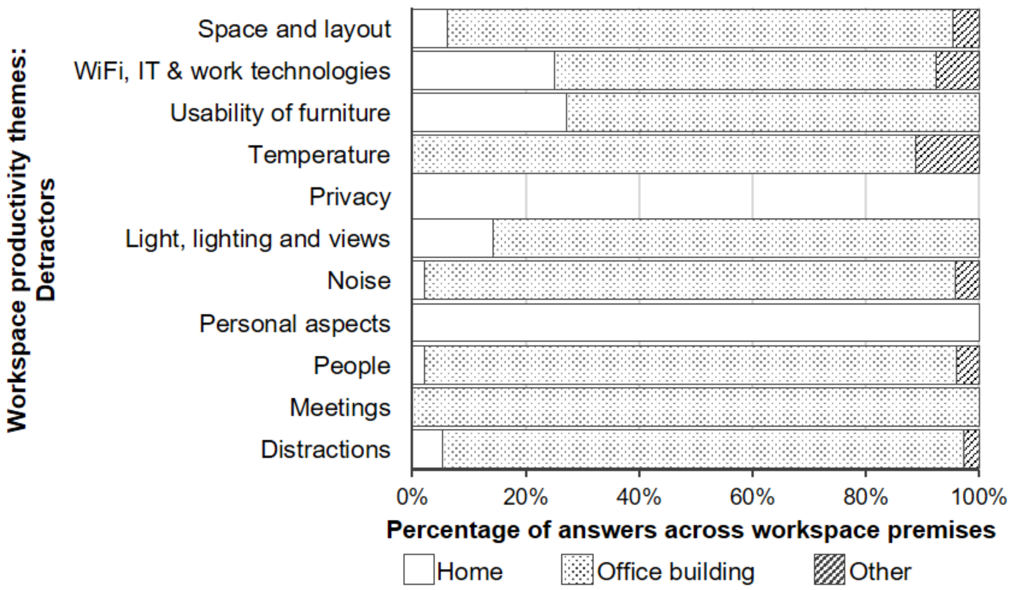
Examples include frequent references to “quiet” spaces, with “limited” or “minimal” distractions. After *Noise*, mentions of aspects related to *Space and layout* were the second most frequent. Some participants described their work settings in the living areas or bedroom as ‘comfortable’ and ‘spacious’, and also as ‘familiar’ or ‘relaxed’ – such words speak of the psychosocial dimensions of using the home for work. Examples from home office users include “[having] *a dedicated desk area, extra monitor and the ability to close the space for privacy*”.

Home offices were particularly described as quiet, private spaces. They were the only home-based settings in which WiFi, IT and work technologies were specifically addressed as being elements conducive to productivity: “similar multiple screen set up like I have in the office”.

4.11.4. Workspace themes: Productivity detractors

Similar charts are plotted to compare the themes associated with negative effects on productivity, as obtained from participants who worked in the office, from home or in other locations. Figure 4-45 suggests that *Distractions,* *People, Noise* and *Space and layout* are predominant themes among office workers, while *WiFi, IT & work technologies,* and *Usability of furniture* are some of the key concerns of home workers. Examples are discussed below.

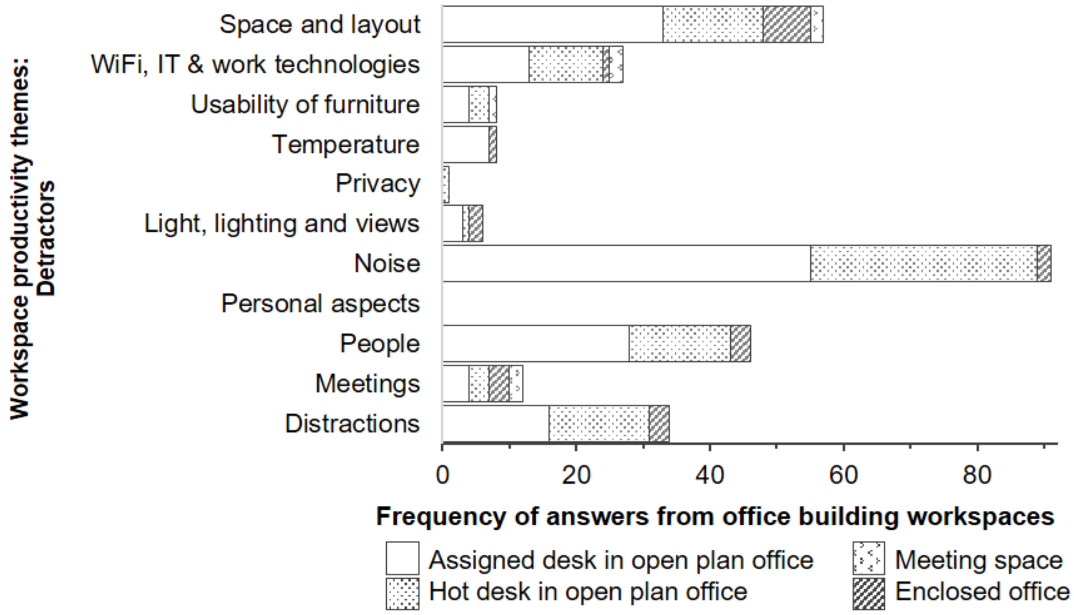
Figure 4-45. Productivity detractors: Themes across workspace locations



(A) OFFICE BASED WORKSPACES

Office workers' responses regarding the disruptive effects of the workspace were more numerous than their answers to the productivity supporters question. Overall, *Noise* was the most prominent theme, with both permanent and hot desk users mentioning its negative effects on productivity (figure 4-46). *Distractions* were also mentioned frequently, predominantly by hot desk users.

Figure 4-46. Productivity detractors: Office based workspaces



The second most frequent theme perceived as being disruptive was *Space and layout*, with examples often related to the presence of other people, privacy, or the use of technology.

- As described by an enclosed office user:

"We had two parallel meetings (Skype and in person) in the office because there were no meeting spaces."

- Examples from hot desk users include:

"It was too open for [the] tasks I was performing. I needed more visual privacy".

- Spatial issues associated to working in open plan offices at a permanent desk often refer to interruptions from other people:

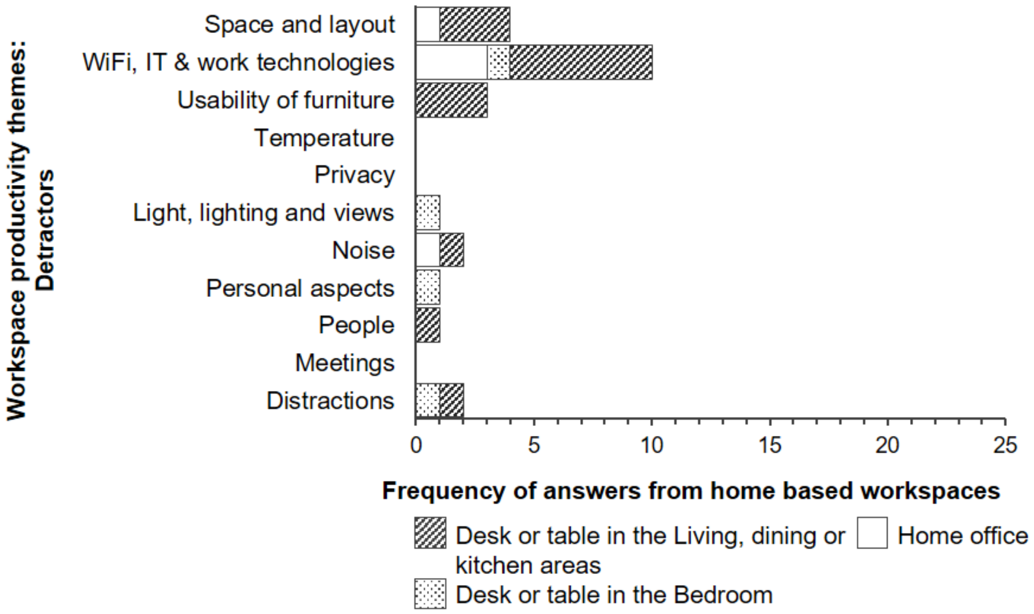
"When in the office & everyone knows where you are, it leads to constant interruptions"

Temperature – either cold or warm - is also seen as an element able to disrupt productivity. Responses referring to environments being 'too cold' or 'too warm' were obtained from open plan workers with permanent desks.

(B) HOME BASED WORKSPACES

Home workers made considerably fewer comments on the disruptive role of the workspace compared to the number of observations on its supportive effects; this is shown by the lower number of responses. Most responses originated from participants who worked in spaces not primarily designed for office work, primarily living areas, and referred to *WiFi, IT & work technologies,* and *Space and layout* aspects (figure 4-47).

Figure 4-47. Productivity detractors: Home based workspaces



Chapter 5. Discussion

Chapter 5 discusses the contributions that this doctoral research has made to knowledge of the relationship between the physical workspace, choice of time and place of work, to productivity and wellbeing. A high-level summary of the WorQ study findings is presented, acknowledging limitations, and suggesting potential implications for workspace users, decision makers, and researchers. Finally, the chapter concludes by suggesting opportunities for future improvements of the methodology.

5.1. Contributions to knowledge

5.1.1. Theoretical contributions: Addressing the ‘workspace’/’workplace’ knowledge gap

The research entitled ‘Productivity and Wellbeing in the 21st Century Workspace: Implications of Choice’ intended to bring together two well-established areas of workspace research that appear to consistently ignore each other due to disciplinary differences. One approach focuses on the physical attributes of the ‘workspace’ environment, but not psychological, social or behavioural dimensions. The other emphasizes psychosocial dynamics within the ‘workplace’, omitting any role that physical parameters might play. Instead, this work adopted an interdisciplinary approach that built on both.

While both schools of thought have conducted empirical research spanning several decades, they offer different answers to the question ‘how does the workspace affect employee productivity and wellbeing?’. The IEQ of the physical workspace arguably enhances productivity and wellbeing outcomes, while psychological constructs such as choice, control or autonomy, may be powerful motivators across many aspects of working life including productivity and wellbeing. *Choice* is a particularly relevant topic in the context of flexible working, considering that a growing number of organisations allow their employees some degree of choice over where and/or when they work. Yet, at the same time, switching between different work settings may introduce new aspects of the role of the workspace IEQ in supporting productivity and wellbeing.

This work is arguably a small step leading towards an integrated theory that unites the physical environment research with the social sciences research. The WorQ study explored physical and psychosocial processes related to workspace productivity and wellbeing: choice of work space and time, and workspace IEQ and control. The study design which used the EMA approach recognised that the processes leading to the productivity and wellbeing outcomes may have different exposure times:

- Momentary ratings of perceived choice of work space and time and workspace IEQ were analysed in relation to cognitive performance (considered as a productivity proxy);
- Average values of choice of work space and time obtained during several days were analysed when exploring effects on wellbeing.

5.1.2. Cognitive learning: A novel metric of knowledge work productivity

This research has also addressed a question relevant to workspace practitioners and researchers alike: *how to measure productivity for knowledge work*. As explained in chapter 2, work performance can be assessed in absolute terms, by relating the inputs and outcomes of work, or indirectly, using comparative measures, self-assessment tools, or proxies. For knowledge work, however, which deals primarily with information and does not typically produce directly countable outcomes, the first option does not apply.

This research brings a contribution to workspace knowledge by collecting evidence using a proxy productivity metric applicable to knowledge work. Considering that “Concentration of the mind is vital for good work performance” (Clements-Croome, 2006: 14), the methodology aimed to objectively assess workers’ *cognitive learning*, i.e. their ability to sustain “high level cognitive activity” (Brinkley et al., 2009: 4) within their work environments.

Findings from a systematic review of academic literature revealed *cognitive performance* to be a suitable proxy for the objective measurement of productivity. However, such approaches only assess the cognitive performance achieved *at one point in time*, under *specific environmental conditions*. Yet, given many workers’ exposure to multiple work environments within the space of a single work day, this approach has some limitations. Perhaps more importantly, cognitive performance approaches do not address the broader process considered crucial for knowledge work, that of *learning*, i.e. acquiring and revising knowledge, and developing skills over time (Drucker,1999).

Furthermore, as shown before, a vast segment of the workforce – those working in low-skilled occupations – may soon become under threat from the development in AI. As recommended by ILO (2019b), *lifelong learning* – i.e. reskilling and upskilling – may be the key to securing employability over time. In the small sample of WorQ study participants who completed the tests for five days (figure 4-29 in chapter 4), those with high choice of work space and time learned *quicker* than those with low choice, in all four cognitive domains. In the workforce, this could be an important advantage in the future.

The knowledge work productivity proxy metric developed for this research assessed *cognitive learning*, operationalised as the performance achieved for several cognitive areas, over time. While the methodology assessed performance on four different cognitive areas using different tests, the output metric represents the average percentage change of scores achieved on the four tests in day 3 minus day 1. Arguably, this percentage change value acts as a straightforward, yet comprehensive indicator of learning. The metric averages performance in four different areas and, therefore, mitigates the impact of within-group differences. Due to natural ability, practice, or both, some participants might already have advanced *language* skills, but not sustained attention; others might have excellent *visual recognition* skills, but weaker language skills etc. The metric can be used for cross-sectional studies of workers with diverse occupations.

5.1.3. Choice of work space and time

The data included employee's descriptions of their degree of choice of work space and time, a phenomenon gaining momentum nationally and globally. Literature from governmental and intergovernmental sources shows a growing consensus that choice of work space (Allen et al., 2004; Hardy et al., 2008), *or* choice of work time (Eurofound, 2017) may be beneficial for employee productivity and wellbeing. However, spatial and temporal dimensions of choice are rarely differentiated in other studies.

To address this, the *WorQ* study gathered data on workers' *choice over when and where they work*, obtaining data from over 400 points in time and space from 129 UK employees, *productivity* (using cognitive learning as a proxy) and *wellbeing* data measured using a robust scale. The Ecological Momentary Assessment method (EMA) adopted for the main part of the study (except the background data) required both cognitive tests and choice / workspace ratings to be completed in the same space at the same time: in the space within which the respondent was working, around lunch break. This enabled the choice/productivity, and choice/wellbeing relationships to be analysed in a relatively straightforward way.

Furthermore, the measurement of choice of work space and time *separately* and *daily*, instead of by an overall measure, created several advantages compared to using overall ratings of choice (such as those used in the UK Workplace Survey, (Gensler Research, 2016).

- Firstly, it enabled the effects of choice of work space, and choice of work time, to be explored separately, in relation to the study outcomes and the other mediating variables. This showed that choice of work *time* might affect cognitive learning. Had an overall measure been used, this would have remained undetected.
- Secondly, the fact that choice was measured daily minimised the potential effect of recall bias. Participants were not asked to evaluate their degree of choice *in general*, but in their workday so far, which is a momentary assessment. Based on these detailed data, average values can still be calculated to obtain an overall choice metric, if required.
- Thirdly, the daily measurements of choice and IEQ also enabled collection of data over a few working days. This revealed that some employees' levels of choice differed from day to day, while others consistently perceived having the same level of choice over when and/or where they worked. On a larger sample, this could reveal work patterns across occupations or perhaps even industries.

5.1.4. Collecting data from professionals who work 'on the move'

The data collection process in the WorQ study relied on a tool that is familiar to most workers in developed economies: the smartphone. This enabled participants to complete the workspace ratings from wherever they worked around lunch time: in their office building, at home, attending external meetings or even while in transit. Furthermore, the use of short and enjoyable brain-training games to test cognitive performance offered participants the advantages of enjoyment through 'gamification'.

The cognitive tests were developed based on knowledge from neuroscience, making them compatible with the demands of academic research.

At the same time, their friendly and – mostly - self-explanatory interface seems to have made participation enjoyable. The game-like design of the tests – and full anonymity of the results – appears to have minimised some of the pressures associated with the feeling of being examined, as noted in the participants' feedback on the study. Similarly, the fact that the cognitive tests were completed on participants' own smartphones, in settings familiar to the participants, may have minimised the effects of working in an unusual setting that subjects might experience in laboratory conditions. All of these elements encouraged participation: 98 participants complied with the requirement to complete the tests for at least three days. Comments from the study feedback section referred to the cognitive 'games' as the best aspect of participating in the WorQ study (mentioned by 28 of 88 participants who completed the feedback question).

While this methodology has specific limitations that should be acknowledged and addressed by future work (as per the following sections), the study has made a promising contribution to workspace research, with a particular applicability for flexible working.

5.2.The WorQ study: Summary of findings

A high-level summary of the findings is listed below.

Choice and cognitive learning (NC=50)

- The cognitive tests sample includes 50 participants who completed workspace ratings and at least three cognitive tests once daily for three days or more.
- Cognitive learning values in day 3 are all positive, ranging from 12% to approximately 1050% (Mean= 195%; StDev=178). Repetition of cognitive tests has a statistically significant effect: scores generally increase with each repetition of the tests.
- Choice of both work space and time (average) revealed no significant effect on cognitive learning. However, choice of work time alone

appears to make a statistically significant positive difference on cognitive learning.

- The workspace mediator: No effects were found when workspace premise, type or perceived IEQ, respectively, were considered as mediators. In contrast, perceived control of workspace attributes appeared to have a statistically significant mediating effect on cognitive learning in the reverse direction than expected. Participants with low choice *and* low control achieved the highest learning values such as 718%.
- Furthermore, statistical tests[37] also suggested cognitive learning is negatively correlated with the nine workspace IEQ attributes analysed for 35 participants.
- Demographic mediators: None of the demographic factors were found to have statistically significant effects on the choice / learning relationship.
- The relationship between the absolute scores obtained at the four cognitive tests during the three study days and the cognitive learning achieved in day 3 is inverse: extremely low first scores lead to extremely high cognitive learning values.

Choice and wellbeing (NW=66)

- The wellbeing sample is comprised of 66 participants who completed workspace ratings for three days[38], and the wellbeing section in the third day.
- The wellbeing scores were grouped using percentile values obtained from the HSE11 study as follows: 8% of the sample have ‘high’ wellbeing, 50% have ‘moderate’ wellbeing and 42%, ‘low’ wellbeing.
- When wellbeing scores are compared directly with choice levels in absolute terms (without any variable grouping), the only statistically significant effect found is the correlation between *choice of work time* and wellbeing.
- When variables are arranged into ranked groups that take into

[37] Fully presented in chapter 4, table 5-12.

[38] Fourteen of the 66 participants only provided choice of work space and time ratings for two days. However, average choice ratings obtained from two, and three days, respectively, are strongly correlated, therefore these fourteen participants were not excluded from the wellbeing sample.

account the respective levels within each ('high' and 'low' for choice and 'high', 'moderate', and 'low' for wellbeing), the relationship between choice of work space and time is positive and statistically significant.

- The workspace mediator: Tests on the mediating role of the workspace on the choice / wellbeing relationship revealed control of workspace attributes to have a statistically significant mediating effect. Participants with high choice of work space and time *and* high control over the attributes of their workspaces tend to have the highest wellbeing scores.
- Demographic mediators: Industry was found to have a significant mediating effect of the choice/wellbeing relationship: high choice participants had higher wellbeing scores across all industries. No other statistically significant effects were found.

Workspace productivity supporters and detractors (N=130)

Qualitative data were obtained from 130 participants who answered two open questions about the workspace elements that support and disrupt the ability to work productively. Most participants were office workers who predominantly used desks in open plan offices; few participants had the possibility to work from home. Using deductive thematic analysis, eleven themes were identified: Noise, Space and layout; WiFi, IT & work technologies; Usability of furniture; Temperature; Light, lighting and views; Privacy; People; Distractions; Meetings; Personal aspects. Seven of the themes refer to physical attributes of the space, and four to psychosocial dimensions of the workspace.

Other insights

At every step of the analysis, the following relationships were found to be positive and statistically significant:

- The degree of choice of work space correlates positively with degree of choice of work time;
- Workspace IEQ correlates positively with control of workspace attributes.

5.3. Choice, cognitive learning and wellbeing: The role of the workspace

The following section discusses the study results in parallel, exploring similarities and differences. Table 5-1 below shows the results of the statistical analysis of the relationship between choice of work space and time, cognitive learning and wellbeing, with no mediators considered. Arguably, choice affects the two outcomes differently. Firstly, choice of work space and time appeared to be positively associated with wellbeing, but not with cognitive learning. Participants with more choice of work space and time have higher wellbeing levels, however did not learn significantly more (or less). Secondly, choice of work time was positively associated with cognitive learning, but not with wellbeing. Participants with more choice of when they work learned more, however did not have significantly higher (or lower) wellbeing.

Table 5-1. Summary of statistical test results: Choice of work space and time, cognitive learning and wellbeing: No mediators (NC=50; NW=66)

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result	Significance
1	Choice of work SPACE and TIME	—	Cognitive learning	Median Test Mann-Whitney	Retain Retain	1.000 0.186
			Wellbeing	Median Test Jonckheere-Terpstra	Retain Reject	0.324 0.031*
2	Choice of work SPACE	—	Cognitive learning	Median Test Jonckheere-Terpstra	Retain Retain	0.799 0.211
			Wellbeing	Median Test Jonckheere-Terpstra	Retain Retain	0.390 0.147
3	Choice of work TIME	—	Cognitive learning	Median Test Jonckheere-Terpstra	Reject Retain	0.048* 0.236
			Wellbeing	Median Test Jonckheere-Terpstra	Reject Retain	0.352* 0.085

***Statistically significant at 0.05 level.**

Furthermore, when the workspace is taken into account as a mediator of the relationship (table 5-2), **control of workspace attributes** is associated with both outcomes significantly. However, the cognitive learning and wellbeing effects are opposite:

- Participants with low choice of work space and time and low control of workspace attributes achieved the highest cognitive learning values, while those with high choice and high control learned the least; (negative association with cognitive learning)
- Participants with high choice of work space and time *and* high control of workspace attributes had the highest wellbeing scores, while those with low choice and low control have the lowest wellbeing scores; (positive association with wellbeing).

Table 5-2.Summary of statistical test results: Choice of work space and time, cognitive learning and wellbeing: The workspace mediator (NC=50; NW=66)

No.	Independent variable	Mediator variable	Dependent variable	Statistical test	Result	Significance
4	Choice of work SPACE and TIME	Workspace Premise	Cognitive learning	Median Test	Retain	0.532
				Kruskal-Wallis	Retain	0.742
			Wellbeing	Median Test	Retain	0.500
				Kruskal-Wallis	Retain	0.331
5	Choice of work SPACE and TIME	Workspace Type	Cognitive learning	Median Test	Retain	0.815
				Kruskal-Wallis	Retain	0.812
			Wellbeing	Median Test	Retain	0.770
				Kruskal-Wallis	Retain	0.468
6	Choice of work SPACE and TIME	Workspace IEQ	Cognitive learning	Median Test	Retain	0.711
				Jonckheere-Terpstra	Retain	0.095
			Wellbeing	Median Test	Retain	0.149
				Jonckheere-Terpstra	Retain	0.177
7	Choice of work SPACE and TIME	Control of workspace attributes	Cognitive learning	Median Test	Retain	0.479
				Jonckheere-Terpstra	Reject	0.037*
			Wellbeing	Median Test	Retain	0.124
				Jonckheere-Terpstra	Reject	0.020*

*Statistically significant at 0.05 level.

However, section 4.6.5 showed that the cognitive learning metric is negatively and significantly associated with the absolute scores. Eleven of the twelve participants in the upper 25% cognitive learning group had obtained at least one baseline score that was low or extremely low (below the 25% or 10% threshold of the tests' ranges). Therefore, the finding '*participants with the* *highest cognitive learning values had low choice of work space and time*' could also be expressed as '***participants with the lowest first scores had low choice of work space and time***'.

A simpler explanation to why low choice participants – who have generally fewer qualifications and report lower levels of job control – outperform their high choice, highly qualified peers, could involve the role of motivation to perform the tasks and, importantly, the availability of time to solve the tasks. Previous examples from the environmental sciences perspectives (Lan et al, 2009; Jahncke and Halin, 2012) have shown that subjects maintained their performance on cognitive tasks even in uncomfortable conditions, if they had a high motivation to solve the tasks. Neither motivation nor availability of time were measured in the WorQ study. It can only be *assumed* that lower choice participants who perhaps work in lower responsibility jobs, may more easily find the time and energy to solve cognitive tasks during their lunch break.

An insight that can also be discussed further is the strong and positive correlation found between levels of choice of work space and time, perceived control of workspace attributes and perceived satisfaction with workspace IEQ. This finding is consistent with theories of social and cognitive development that emphasize the importance of choice, control and autonomy (Bandura, 1997; Ryan and Deci, 2000). A possible explanation could be that choice and control use the same neural circuitry, as shown by neuroscience research evidence (Leotti et al., 2010; Leotti and Delgado, 2011). Another possible explanation would be that employees with higher levels of seniority – those who tend to have the most choice – also have access to better workspaces.

Perhaps a surprising finding of the qualitative data analysis was that some aspects clearly marked by the literature as important for productivity and wellbeing were absent. Air quality and plants were not mentioned by any respondents as possible supporters or detractors of productivity. The absence of 'air quality' could perhaps be explained by the fact that subtle changes in air pollutants are not easily detectable by human senses alone. The absence of 'plants' is surprising, considering findings from other large scale studies such as that of Cooper and Browning (2015). However, this could be related to the phrasing of the questions in the WorQ study, which unlike the 'Human Spaces' study, was inductive, and did not specifically investigate biophilia (or any other particular aspects of the workplace).

5.4.Limitations of the findings

The limitations of the WorQ study findings should be acknowledged. Most of these limitations are of a methodological nature, drawing on the sample size and characteristics; other limitations resulted from the interpretation of the findings.

5.4.1. The sample size: Recruitment, dropout rates and exclusion

The sample sizes obtained for the quantitative study outcomes are relatively small: 50 for cognitive learning, and 66, for wellbeing. However, as revealed by the systematic review of literature (section 2.3), earlier studies with similar scope or methodology tended to be conducted on smaller samples:

- Wei *et al.*, (2014) used an EMA approach to conduct empirical research into the effects of office lighting on employee productivity on 26 participants over three months;
- Lan et al., (2009) studied the effects of indoor air temperature on perception, learning and memory, thinking and executive functions, on 24 participants in laboratory settings;
- Haka *et al.*, (2009) examined the impact of speech on cognitive performance in a laboratory experiment with 37 student participants.

As discussed in Chapter 4, the study adopted an ecological momentary assessment research design which used digital consent forms, online surveys and a 'brain-training' smartphone application to collect data. This led to a decrease of the sample size at every step of the process. The WorQ study followed the ethical and data protection requirements of doctoral research (Appendix C), which require the use of several platforms for collecting different types of data. Under different circumstances, a different study design could ensure the protocol is streamlined and has fewer steps, which could minimise the drop out rate.

- First, the WorQ recruitment process required different actions to be performed at different times, and different emails and documents to be circulated from different senders, some external to the company by which the participants were employed. For example, the email that contained essential login information may have been blocked automatically by the companies' IT protection systems. This could explain why of the over 2,000 *intended* recipients of the invitation email, only 313 signed the consent forms.
- In the week before data collection began, potential participants were required to read the project information sheet, 'sign up' by virtually signing the consent form, and install the app using specific login details. Many participants may have forgotten about the study by the following week, or were too busy. This could explain why from the over 300 participants who signed up to the WorQ study, just 150 started completing the cognitive tests and/or surveys.
- Once participation started, the dropout rate increased further, as some participants did not complete the tests and/or workspace ratings a sufficient number of times. However, the main determinant of the final sample sizes was the exclusion of participants from the analysis for methodological reasons. The EMA design of the study required that the independent and one

of the dependent variables (cognitive learning) are measured at the same time, in the same space. Therefore, data from participants who completed the tests but not the workspace ratings (or vice versa) were excluded from the choice and learning analysis: this reduced the sample size from 98 to 50. Similarly, data from participants who completed the wellbeing section without providing sufficient workspace ratings were also excluded: this reduced the wellbeing sample size from 88 to 66. Finally, the main analysis excluded participants who did not complete the demographic information.

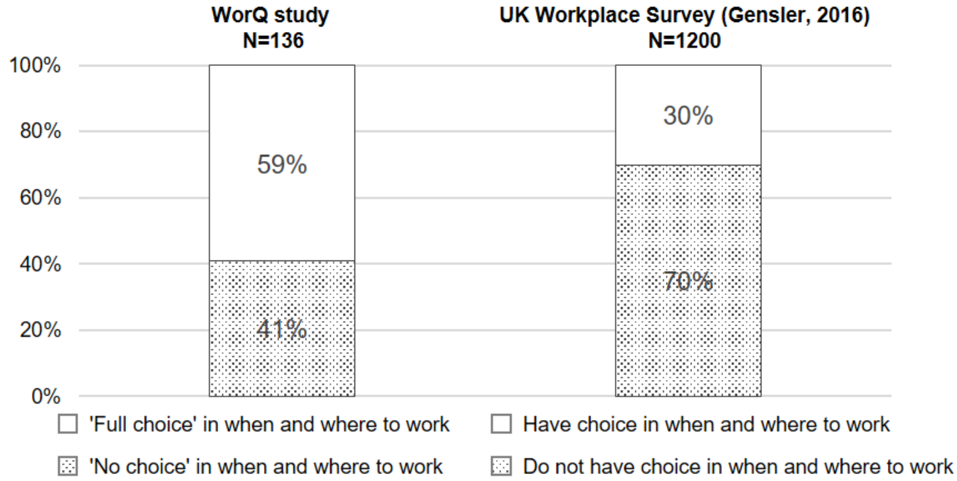
5.4.2. Comparison with other samples

Wherever possible, the study sample was compared against larger sample studies, to explore whether any of the characteristics of the WorQ sample are representative of the much larger population of UK-based office workers.

(D) CHOICE OF WORK SPACE AND TIME

The workspace choice data collected in the WorQ study (N=136) were compared to the results of the *UK Workplace Survey* conducted by on a sample of 1,200 workers across 11 industries (Gensler Research, 2016). While methodological details are not fully presented in the Gensler report, the study appears to have measured the degree of choice in when and where to work using a dichotomous scale ('have choice' / 'do not have choice'). As the WorQ methodology used a seven-step scale ranging from 'No choice' to 'Full choice', only these two extreme values were considered for this comparison. Percentages were calculated based on these data, i.e. the 93 *average choice of work space* and *time* observations with values of either 1 or 7. As shown in figure 5-1, the WorQ sample includes a larger proportion of participants who had 'full choice' over when and where they work: 59%, compared to the 30% UK Workplace Survey participants who reported 'having choice'. Consequently, a smaller percentage of participants had ‘no choice’: 41%, compared to 70% in the Gensler research. The sample of the WorQ study includes **almost twice as many workers with high levels of choice** than those included in the Gensler Research study. However, the two studies used different methodologies. To correspond to the UK Workplace Survey’s dichotomous scale, only the *extreme values* from the WorQ sample were used in the comparison. <u>This is an important limitation of the comparison.</u>

Figure 5-1. Choice of work space and time: WorQ study sample (N=136) and UK Workplace Survey (Gensler, 2016) (N=1,200).



Furthermore, the recruitment process relied strongly on participants’ time and willingness to spend a few minutes every day playing games on their smartphones, while being in the workspace. Professionals with high levels of autonomy are perhaps most likely to have this possibility, therefore the generally high choice levels of the sample might not be a coincidence. **Self-selection bias is a limitation of the study.**

(E) WELLBEING

Table 5-3 and figure 5-2 are used to draw a comparison between the wellbeing scores collected in the WorQ study (general sample) and those obtained from the Health Survey for England 2011 (‘HSE11’), a cross-sectional survey of the population with a nationally representative sample (Warwick

Medical School, 2014).

Table 5-3. Comparison of wellbeing results: the WorQ study and Health Survey for England 2011

Statistic		WorQ study	Health Survey for England 2011
*N	Valid	88	7196
Mean		22.19	23.61
Std. Error of Mean		0.31	0.05
Median		21.95	23.21
Std. Deviation		2.90	3.90
Skewness		1.17	0.18
Std. Error of Skewness		0.26	0.03
Kurtosis		3.44	1.45
Std. Error of Kurtosis		0.51	0.06
Minimum		16.88	7.00
Maximum		35.00	35.00
Percentiles	25	19.98	21.54
	50	21.95	23.21
	75	24.11	26.02

* Based on Warwick Medical School (2014).

- The two distributions appear to be different. While the HSE data are normally distributed (judging by the skewness and kurtosis values), the WorQ study data are not, as shown by statistical analysis[39].
- The mean and median values of the WorQ sample (22.19, and 21.95) are lower than in the HSE11 sample (23.61, and 23.21). The percentile values of the distribution are also significantly lower.
- The ranges of the two distributions are also significantly different. While the HSE data are spread between the minimum and maximum values of the scale (7, and 35, respectively), the range of the WorQ study data is narrower (16.88 to 35). The standard deviation of the WorQ sample is also lower than that of the HSE11 (2.90 compared to 3.90), which suggests the data are more consistent or similar.

Considered together, these findings suggest that the wellbeing data of the WorQ study are generally less varied, *and tend to be situated within the lower to central area of the spectrum* described by the HSE11 sample.

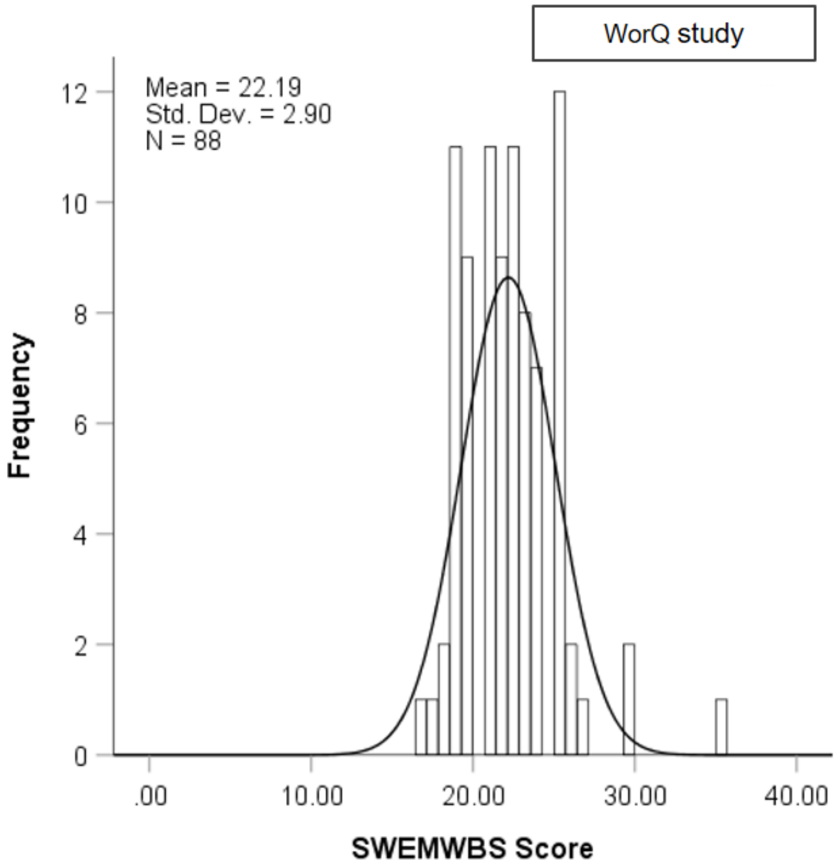
While the two samples are very different in size – the WorQ study sample represents approximately one percent of the HSE11 sample – they may still be comparable from a demographic perspective. The cross-sectional HSE11

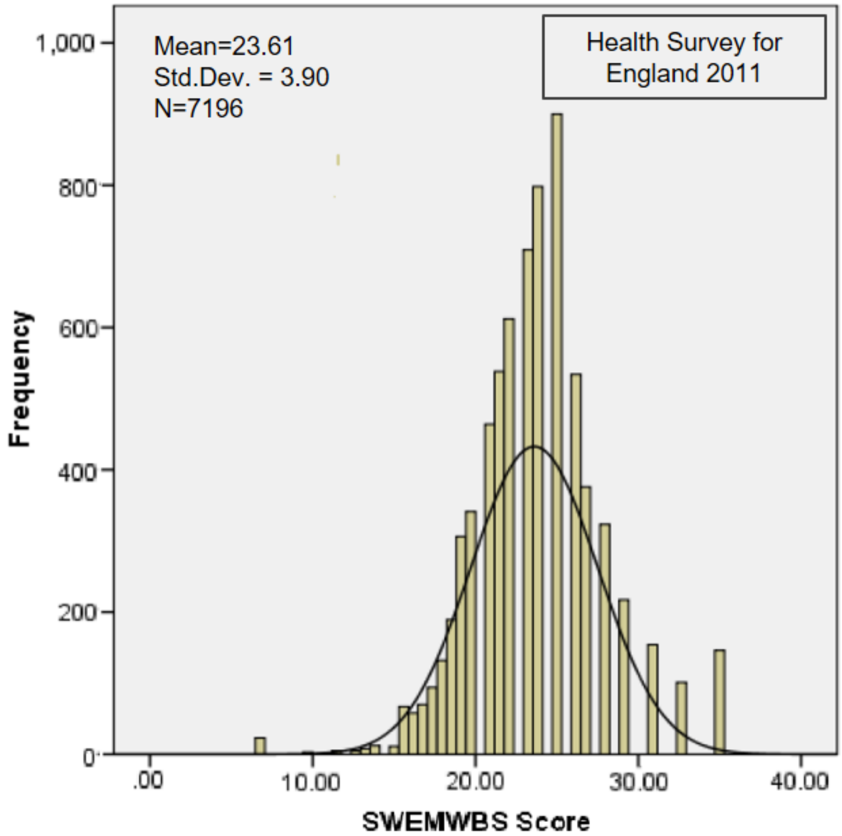
[39] One-sample Kolmogorov-Smirnov test, significance 0.023.

sample includes wellbeing data obtained from adults of working age (16 or over), most of whom are in some form of employment. This includes a wider variety of jobs than the very specific, office worker sample of the WorQ study.

Figure 5-2. Comparison of Wellbeing scores distributions in the WorQ study and Health Survey for

England 2011 (Adapted from Warwick Medical School, 2014)





5.5. Implications of study findings

Based on the findings of the study, several recommendations can be suggested for organisations, managers, and their HR and FM decision makers**.** It should however be acknowledged that these recommendations are based on *correlation* effects observed in the study, which do not necessarily imply causality. Additional factors explored by the literature but *not measured* in the WorQ study – such as job satisfaction, physical or mental health - might have contributed to the relationships.

1. Allowing employees more choice of work space and/or time may have positive effects on their wellbeing.

The need for choice, control and autonomy - which are “biologically motivated” - are believed to be critical for individual wellbeing (Leotti and Delgado, 2011: 1315). Findings from 66 WorQ study participants appeared to confirm this relationship: participants’ degree of choice of work space and time were significantly associated with their wellbeing, when variable grouping was applied. Among the five High wellbeing participants, most had high choice of work space and time (n=4 or 80%), and one has low choice. In contrast, the 28 Low wellbeing participants included almost twice as many participants with low choice of work space and time (n=18) than high choice (n=10).

2. Allowing employees more choice of work *time* could have positive effects on their productivity and wellbeing.

If allocating choice over space of work is not a viable option, implementing some degree of flexibility regarding *time of work* is likely to have beneficial effects for both wellbeing and the ability to work productively. Significant associations were found between choice of work time and both of the study outcomes: participants with higher choice of work time tended to learn more and have higher wellbeing scores.

By introducing flexible working hours, employees can perhaps manage their time in a way that better suits their lifestyle, have a better work-life balance and, become more efficient in their professional life.

3. Allowing employees more choice of work space and/or time may increase their satisfaction with the workspace.

A strong and positive correlation was found between choice of work space and time, perceived control of workspace attributes and perceived satisfaction with the quality of the workspace environment. These findings are consistent with theories of self-efficacy and self-determination (as explained in chapter 2), which suggest feelings of choice are generally associated with satisfaction. In a practical way, this suggests that employees may be more satisfied with work environments upon which they are able to exercise choice, or control over their attributes.

Based on the WorQ study findings, further recommendations can be made regarding the design and management of office space:

4. Implement workspace strategies that enhance choice and perceptions of choice., e.g. some home working and a choice of workspace when in the office.

As shown above, a key recommendation of the study is to introduce policies that offer choice and control over work space and time. Although the final WorQ sample was small, the highest participant ratings of choice of work space and time, IEQ and control of workspace attributes were obtained when working from home. The WorQ study also found that participants who used hot desks rated their levels of choice, control and IEQ higher than those who used permanent desks. This corroborates with findings from a large sample study (n=3,974) of desk ownership in open plan settings and occupant satisfaction (Kim et al., 2016). Their study found that hot desk users consistently outscored permanent desk users, offering higher ratings of satisfaction with 16 out of the 18 measures of IEQ considered.

Most open plan office respondents considered noise, distractions, and space and layout to have negative effects on their ability to work productively. All these effects can be reduced by simply moving to a different, perhaps quieter, workspace area assuming one is available but this option may not be applicable to those who use an assigned desk in a setting in which all desks are allocated to individuals and in effect cannot be used by others.

5. Create and allow access to a variety of spaces within the office building suited for different activities.

Qualitative data obtained from 125 participants who worked in their office building suggested that *Distractions, People, Noise* and *Space and layout* are the most common productivity disruptors. Many of the perceived disadvantages related to the first three aspects, may in fact, be addressed by a more thorough revision of the *Space and layout*. The need for more, and, perhaps, enclosed, meeting spaces was addressed by some participants. Others referred to the lack of visual privacy of the open plan office: “It was too open for [the] tasks I was performing. I needed more visual privacy”.

The need to adapt office space to work requirements – and not the other way around – may become a growing problem as flexible working becomes widespread. Ideally, space should be designed based on the specific requirements and work patterns on the space occupants, however this may not be always possible. Instead, a possible solution could be to allocate less space to permanent desks (which, based on the WorQ study, did not reveal any advantages), and more space, to areas equipped for solo work, meetings and workshops. These should be of different sizes and have, if possible, the option to become enclosed, to facilitate privacy and concentration.

6. Ensure that employees have adequate access to the necessary work technologies and appropriate work settings when working from home.

Qualitative data obtained from 33 WorQ study participants when working from home suggested that *WiFi, IT & work technologies*, and *Usability of furniture* are some of their key concerns. Companies who allow home working should perhaps provide their employees with the right tools. Organisations facilitating home working should ideally also assist employees with creating home-based settings that are indeed compatible with prolonged office-type work.

5.6.Recommendations for further research

The WorQ study revealed some potentially valuable insights into the effects of choice on productivity and wellbeing in the workplace context, however further research is required to validate these findings.

Firstly, further research should be conducted on a larger sample. Some of the relationships revealed – particularly cognitive learning – were likely to have been affected by the size of the sample. In a larger sample, the effects of outliers would be smaller and the trends observed, more robust.

Secondly, the study design should be demographically controlled to obtain a more representative image of the UK knowledge worker population and minimise the possibility of self-selection bias. Occupational skill levels may be particularly important for assessing cognitive learning. As shown by Brinkley *et al.* (2009) a third of the UK workforce is comprised of high knowledge, intensive jobs, however job titles or levels of qualifications are not usually indicative of this.

Perhaps the recruitment protocol could include a stage that collects information on participants' most frequent professional tasks.

Thirdly, to minimise the effects of extremely low first day scores the cognitive learning metric could perhaps consider the first testing day as a 'practice' session and omit the results, taking day 2 scores as the starting point. Additionally, on a larger sample, the effect of outliers could be reduced.

To maximise the use of data and reduce participant drop out, future research should, as much as possible, either use a single platform to collect all of the data and/or develop an effective system of notifying participants to complete the tests and ratings. The use of smartphone applications to gather data is becoming increasingly common and has particular advantages when studying 'work on the move'. However, this should be balanced with concerns for personal data security and anonymity, especially when deploying sensitive cognitive data and ratings.

5.7. Potential benefits of choice of work space and time

A few further remarks can be made based on the WorQ study. Choice is known to be related to perceptions of control even when actual control is absent (Leotti et al., 2010), so choice might activate the short and long-term qualities of wellbeing and productivity. Short term implications refer to the possibility of using choice of space to support different requirements, such as selecting a space suited to conducting either focused, or collaborative work. Given the choice, employees can select quiet areas when they need to concentrate on isolated work, or collaborative spaces for group work, all of which may contribute to productivity.

Sustained choice over a longer period could also contribute to wellbeing. Enabling employees the possibility to tailor their work schedule so as to accommodate the demands of personal life may contribute to their life satisfaction. Additionally, it may enhance the organisation's reputation. According to a Deloitte's *Millennial Survey* respondents, successful companies are those that "Ensur[e] employees feel comfortable…where people are free to perform their tasks and duties regardless of time and space" (Deloitte, 2016). Offering employees workspace choice can be a signal of trust. Perhaps in time, trusting employees with the choice of when and where to work may help create a workspace culture of empowerment - arguably a defining characteristic of high-performing organizations (Great Place to Work, 2016).

5.8.Further remarks

The Workspace Choice and Quality study found limited evidence to support the claim that choice of work space and time impacts short term cognitive learning, however it suggested a possible – and positive – association with wellbeing. **Of the two findings, the latter may be more important for the long term, sustained productivity crucial for maintaining organizational success and national development.**

As shown by the review of literature, many factors in the workspace environment can affect short-term cognitive performance and concentration, including - but not limited to - physical parameters like temperature, air quality, light or noise, or psychosocial dimensions such as motivation or feeling observed. Choice of work space and time may or may not be one of these factors. However, short-term concentration may be important for productivity, but it is not its only ingredient, nor should it be considered as its *only* marker.

Instead, the author believes, there may be more gain from focusing on the long-term effects of the workspace on wellbeing, a likely *precursor* of productivity. If choice of work space and time have similar effects to those signalled by the *choice, control* and *autonomy* literature, then choice will strengthen the cognitive and motivational mechanisms associated with both wellbeing and productivity. In addition to the clear financial and sustainability advantages to companies of reducing space requirements per employee, allowing employees a greater degree of choice over where and when they work could support their personal and professional growth, which is likely to benefit the organisation.

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Chapter 6. Conclusions

6.1. Workspace productivity and wellbeing: Importance and knowledge gaps

Productivity and wellbeing are key elements of economic growth and human development, at national and organisational level. Industrial productivity metrics include the relationship between inputs and outcomes of work, such as gross domestic product (GDP) per capita, GDP per number of jobs, or GDP per hours worked. However, this approach is not suitable for knowledge work, a quality-orientated process which cannot readily be measured by quantifiable outputs. The high (and growing) percentage of knowledge workers within the services sector makes the development of adequate productivity metrics a pursuit with valuable implications for the global and UK economy. The first objective of this research was therefore to develop a productivity proxy metric suitable for application to the work of Knowledge workers. Instead of quantifying the outcomes of work directly, this metric seeks to enable assessment of the psychosocial and environmental conditions within the workspace that might enhance productivity and wellbeing.

The current state of knowledge regarding workspace productivity and wellbeing is supported by a growing body of evidence but includes a major gap, that between the environmental sciences approach and the social sciences approach.

The first approach implicitly sees the quality of the physical workspace environment as a key determinant of productivity and other related outcomes. Parameters such as temperature, air quality, noise, light and lighting, spatial characteristics of the space, as well as cleanliness and maintenance are commonly discussed as having an impact of productivity and wellbeing (particularly on its physical health component). However, the psychological, intangible mechanisms within the workspace – such as those associated with feelings of autonomy and control - are rarely considered.

In contrast, the second approach implicitly allocates importance to the psychosocial dimensions of the workplace. In work and in personal life, choice, control, and autonomy are believed to lead to higher motivation, cognitive and social development, self-actualisation and wellbeing. However, the role of the physical environment is not addressed.

In the knowledge economy, some/many? employees are increasingly able to switch between various work settings and times. This implicates both the physical environment(s) used, and the psychosocial effects associated with exercising choice and control. Therefore, the key research question of this work addresses this gap:

> Does the ability to choose when and where to work affect employee productivity and wellbeing? How does the quality of the workspace contribute to this relationship?

6.2.Choice of work space and time, productivity and wellbeing: A new methodology

Based on methods and tools revealed by the review of relevant academic literature, a novel methodology was created in order to reach the research objective and address the knowledge gap. The *Workspace Choice and Quality study* ('WorQ') explored the relationship between office workers' *choice of space and time of work*, their *productivity* and their *wellbeing*, with the workspace acting as a potential mediator.

According to self-efficacy and self-determination theories, one of the key benefits of choice, control and autonomy is learning. At the same time, learning is one of the key requirements of knowledge intensive work which frequently faces workers with adapting to new information or circumstances. Further, cognitive performance is a metric commonly used by workplace productivity researchers. The WorQ study developed a proxy metric for productivity applicable to knowledge workers, by assessing cognitive learning, i.e. taking repeated measures of cognitive performance over a set period of time. To account for the individual differences between cognitive skills, an average metric of learning was developed based on performance on four cognitive tests included in a cognitive training 'app' or application on a smartphone.

The study adopted an ecological momentary assessment methodology for testing cognitive learning, using ratings and cognitive tests completed in the workspace, daily around lunch break for a duration of five days:

- Ratings of the perceived choice of work space and time and the workspace used in the previous hour, and information on workspace premise, type, IEQ and control of attributes were collected via surveys.
- Cognitive learning was calculated as the average percentage change on four cognitive tests' scores obtained in day 3 minus those obtained in day 1.
- Wellbeing was measured in the day 3 survey using a robust and well-validated scale, SWEMWBS scale.

6.3.Summary of results and discussion

Results of the WorQ study suggested that choice of work space and time may have little effect on productivity operationalised as 'cognitive learning' but appeared to be positively associated with wellbeing. However, choice of work *time* appeared to produce significant positive effects on cognitive learning, i.e. participants with higher degrees of choice over when they worked tended to learn more.

One aspect of the workspace environment appears to mediate the relationship between choice and the two outcomes. Surprisingly, that aspect is not IEQ. Instead, it seems that **Control of workspace attributes** is significantly associated with both outcomes, albeit in opposite directions:

- **Negative association with cognitive learning**: Participants with low choice of work space and time and low control of workspace attributes achieved the highest cognitive learning values, while those with high choice and high control learned the least;
- **Positive association with wellbeing**: Participants with high choice of work space and time *and* high control of workspace attributes had the highest wellbeing scores, while those with low choice and low control have the lowest wellbeing scores;

The former finding is contradictory to theories from the social sciences, which posit the beneficial effects of control, choice and autonomy (Bandura, 1997; Ryan and Deci, 2000). In contrast, the latter finding is consistent with these theories. Considered together, these findings suggest that choice of work space and time may not necessarily produce short-term effects i.e. cognitive performance, however could be implicated in longer term processes such as wellbeing.

In the smaller sample who completed the tests for five days, participants who had high choice of work space and time learned quicker than those with low choice. While this finding is not conclusive, it does not exclude the possibility that choice may in fact support learning. In a future when AI may take over the majority of repetitive tasks, learning could be an advantage for those in low-skilled occupations, who need to reskill and upskill in order to maintain employability (ILO, 2019b).

The study also found positive and strong associations between degrees of choice of work space and time, perceived control of workspace attributes and perceived satisfaction with workspace IEQ. While these findings are consistent with choice, control, and autonomy theories, they also highlight that the four variables may have confounded each other in this study.

6.4.Limitations and future work

The study was conducted on samples of 50 (for cognitive learning) and 66 (for the wellbeing outcome). While these samples are larger than many of the related studies revealed by the literature review, they are too small to demonstrate conclusive relationships, given the complexity of the topic.

The data collection phase involved complex processes that contributed to a high dropout rate. A different study design with fewer obstacles might maintain a higher sample through all stages of the study.

Additional variables that could affect the relationship under investigation could be measured in further research, such as motivation and the availability of time to complete the tasks (relevant for cognitive learning). Future work could also make use of additional methods, such as direct observation or physical measurements of the workplace, or wearable devices to measure physiological responses. Interviews and focus groups would capture the view of knowledge workers themselves and would reveal additional relevant factors not discussed here.

For these reasons, this research suggests that choice over work space and time - an underexplored, yet increasingly important phenomenon in the knowledge economy - should be the focus of future workspace research designed to overcome the limitations of the present work..

6.5.Implications of the findings

Based on the findings of this research, several recommendations were made for organisations, managers, and those interested in enhancing employee productivity and wellbeing.

- Implementing policies that accentuate personal choice of work space and time might lead to beneficial effects for employee wellbeing.
- Significant effects were found between higher levels of choice of work time and cognitive learning.

This dissertation brings a contribution to workspace theory by addressing the knowledge gap between the environmental and social sciences' approach to the workspace. This work is a step towards integrating these two views into a holistic model of the workspace. Based on insights from the literature and the WorQ study, perhaps a more comprehensive approach to workspace productivity and wellbeing can be formulated.

Choice of work space and time may allow the possibility to exercise – or *perceive* having - control over the physical and psychosocial features of the workspace, e.g. the possibility to move towards spaces with desirable features or away from spaces that are undesirable. This contributes to both physical dimensions of comfort related to environmental or spatial parameters, and also to psychological comfort – i.e. the possibility to seek interactions or avoid distractions.

Choice of work space and time may also enhance feelings of being in control of one's life, which, according to the literature, reflect on job satisfaction and motivation. Although based on a small sample, the WorQ study suggested that choice of work time may be associated to learning and was also described by participants as leading to a better work-life balance.

While further work is required to gather evidence supporting these insights, this research suggests that choice of work space and time are related to both productivity and wellbeing, and the workspace accentuates the strength of this relationship.

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Appendix A.

Hanc M (2016) Workspace choice and control in office settings. In: *Proceeding of the World Workplace 2016 conference: Academic and Research Track* (ed. International Facilities Management Association (IFMA), San Diego, CA, 2016, pp. 60–67. IFMA Foundation.

Workspace choice and control in office settings

Abstract

A growing number of organizations now offer their employees the possibility to choose when and where they work, within on beyond corporate workspace boundaries. This maximizes the role of individual choice, which is often associated with psychological or cognitive benefits. The paper explores the gap between the research literature focused on psychosocial or on environmental workspace aspects and its implications for the growing trend to create flexible office workspaces. It investigates the construct of 'workspace choice', defined as the ability to choose when and where work is performed. The focus of the paper is on findings from the research literature and preliminary insights obtained from a small sample pilot study. This data form one part of a doctoral research project conducted at University College London.

Keywords: choice, cognitive performance, flexible working, wellbeing, workspace choice.

Introduction

Occupier organizations, property developers, FM professionals and designers of office space are interested in creating and managing workspaces that enable occupiers to work productively and contribute to their wellbeing, but the role of the physical workspace is becoming unclear as work technologies – and work itself- are changing. The term 'workspace' (or workplace) now designates a range of options “that extend beyond the domain of the «office» to the home and to a host of «hot-spots« in public venues available within the city” (Cole, Oliver and Blaviesciunaite, 2014: 787). A growing number of organizations now permit their employees to work anytime, anywhere within or beyond the corporate office building, thereby saving space, commuting time and other resources.

Findings from the UK’s Chartered Institute of Personnel and Development (CIPD, 2016) suggested employees who work flexibly were more satisfied with their work-life balance than employees with no flexible work opportunities. E-workers interviewed by Grant et al. (2013) suggested that having the possibility to work remotely enhanced their productivity, increased their sense of confidence and reduced their absenteeism, while also improving their work-life balance and home relationships. A study on the impact of activity-based working (ABW) in 598 workplaces showed that employees with ‘high mobility’ work styles reported the highest productivity (Leesman, 2016). These new flexible ways of working - whether part-time, flexi-time, activity-based working or homeworking - emphasize the role of individual choice.

The concepts of choice, control or autonomy have widely been discussed in psychosocial literature as being conducive to motivation, learning, wellbeing or satisfaction outcomes. However, one particular aspect of choice - the ability to select work environments - is as yet little understood. This paper explores the gap between the research literature focused on psychosocial or on environmental workspace aspects. It discusses the construct of ‘workspace choice’, defined as the ability to choose when and where work is performed, and seeks to clarify whether - and to what extent - workspace choice fosters positive individual outcomes.

The Role of the Built Environment

Environmental sciences researchers commonly discuss the impact of the physical features of the workspace on outcomes such as productivity, performance or comfort. Recent examples include the effects of workspace temperature (Valančius and Jurelionis, 2013), air quality (Lan, Lian and Pan, 2010), light and lighting (Smolders and de Kort, 2014), acoustics (Kaarlela-Tuomaala et al., 2009), or office layout (Haynes 2008). Other researchers investigated the relative benefits of 'lean' (no indoor plants or decoration) and 'green' (indoor plants) offices on employee productivity and workplace satisfaction (Nieuwenhuis et al., 2014) or the effects of managerial control of space on employee satisfaction and wellbeing (Knight and Haslam, 2010). In general, there is broad agreement that the built environment influences outcomes such as performance or productivity, however some approaches investigate the environmental parameters in isolation, and often under controlled conditions. Yet the office workspace is not a static environment: all of these environmental parameters coexist and change constantly throughout the day, along with activity, occupancy rate, or personal preference. Furthermore, the workplace is also a psychosocial environment: behavioral aspects of the workspace such as interaction or distraction may be more relevant to productivity than the physical attributes of space (Haynes 2008).

The Roles and Mechanisms of Choice

Human agency, control and the environment

In the agentic perspective adopted by Bandura's Social Cognitive Theory (SCT), people's beliefs in their capability to exercise control over their lives - or self-efficacy beliefs - are central to human existence, as they "affect the quality of human functioning through cognitive, motivational, affective, and decisional processes" (2012, p.13). Moreover, human functioning is determined by the dynamic interplay of personal, behavioral and environmental determinants. According to their "modifiability" (1997: 163) - i.e. the degree of control individuals exert over them - environments may be either imposed, selected or created. Created environments "enable [people] to exercise greater control over their lives" (p.163), while imposed environments, over which individuals have little control, have an effect on people regardless of their will. However, "within the same potential environmental structure, people can create beneficial or detrimental environments depending on their efficacy beliefs" (: 294). With respect to learning, SCT's agentic view proposes that, by selecting and constructing environments, people activate motivational and self-regulatory mechanisms which promote their cognitive development; while much of the learning may be "socially situated, after people develop self-regulatory capabilities, they learn a lot on their own" (:". 227).

Choice as a vehicle for perceived control

Leotti et al. (2010) propose that choice is generally desirable, as it "allows organisms to exert control over the environment by selecting behaviours that are conducive to achieving desirable outcomes and avoiding undesirable outcomes" (Leotti, Iyengar and Ochsner, 2010); consequently, restriction of choice is aversive. Interestingly, choice may act as a vehicle for perceiving control, which makes it effective even in situations when actual control is absent. Perception of control, suggest Leotti and colleagues, adapts across numerous psychosocial circumstances, and is implicated in regulating emotional responses to various situations - for instance in stressful situations, it may modulate emotion by reducing negative affect. This was explained by the effect of choice over the two interconnected areas of the brain implicated in both affective and motivational processes - the prefrontal cortex (PFC) and the striatum - namely the fact that choice uses the same neural circuitry. Thus "choice in itself may be inherently rewarding" (Leotti, Iyengar and Ochsner, 2010).

Self-determination and intrinsic motivation

Ryan and Deci's Self-Determination Theory (SDT) (Ryan, Ryan and Deci, 2000; Deci and Ryan, 2008) is a macrotheory of human motivation, development and wellbeing. SDT distinguishes between two types of motivation leading to very different effects: autonomous or controlled (Deci and Ryan, 2008). Intrinsic motivation, or the "natural inclination toward assimilation, mastery, spontaneous interest, and exploration that is so essential to cognitive and social development" (Ryan and Deci, 2000: 70) is enhanced by choice, feelings of autonomy and opportunities for self-direction. In contrast, controlled motivation equates to "pressure to think, feel, or behave", and leads to lower psychological health and performance (Deci and Ryan, 2008). In a workspace study, managers' support of subordinates' autonomy produced positive ramifications on employees' perceptions and satisfaction (Deci, Connell and Ryan, 1989). Field experiments conducted by Vansteenkiste et al. (2004) on high school and college students found that intrinsic goals and autonomy-supportive learning climates lead to higher learning, performance, and persistence outcomes than extrinsic goals and controlling environments. Meta-analytic evidence from 41 studies revealed that choice enhanced intrinsic motivation and associated outcomes including task performance (Patall, Cooper and Robinson, 2008).

Job control, demands and stress

In the workplace context, Karasek and colleagues (Karasek, 1979; Karasek and Theorell, 1990) proposed that "mental strain results from the interaction of job demands and job decision latitude" (1979: 285). Specifically, the model postulates that the combination of low decision latitude and high job demands is associated with mental strain and job dissatisfaction, where 'job decision latitude' is understood as the "potential control over [one's] tasks and [one's] conduct during the working day", (1979, p.289). The model measures decision latitude and psychological demands, as well as other aspects such as social support, physical demands and job insecurity. However, this widely used model largely omits the role of the physical workspace environment and the issue of control over when work is performed.

Workspace Choice, Cognitive Performance and Wellbeing: A Pilot Study

Design / methodology and sample

As part of a doctoral research project conducted at University College London (UCL), a pilot study was conducted on a small sample of employees to test whether higher workspace choice may lead to better cognitive learning capacity and higher levels of wellbeing; the potentially mediating role of workspace IEQ was also explored. The project was covered by UCL Data Protection registration. All of the data were collected in November 2015.

The study used an online questionnaire, an online diary survey and smartphone game. Web links to the relevant webpages were circulated internally within the four participating companies and participation was voluntary. The 'Workspace choice' independent variable was measured using a four-point scale via the online questionnaire, which also collected demographic information and included an invitation to the five-day study, as well as an informed consent form. All respondents who signed and returned the consent form via email were accepted to take part in the five-day diary and game study.

For five consecutive work days, participants completed an online diary and played a cognitive game on their smartphone; both actions were performed at the end of each work day. The diary collected data on the perceived IEQ of the workspaces participants used during the work day; IEQ was measured daily using five-point satisfaction scales. In the last study day, Wellbeing was also measured via the diary using the Warwick-Edinburgh Mental Wellbeing Scale (WEMWBS, Tennant et al. 2007). Permission to use WEMWBS was granted by Warwick University.

Cognitive learning was assessed using one of the games of the Great Brain Experiment smartphone application (Brown et al., 2014; UCL Wellcome Trust Centre for Neuroimaging and WhiteBat Games, 2014). The ‘How much can I remember?’ game tests working memory (i.e. the ability to maintain focus). Study participants played the game once at the end of each workday and emailed the score to the researcher; the app was free to use. The measure of cognitive learning was taken to be the percentage increase between the baseline score (first shared score) and the highest score achieved throughout the five days; this was only calculated for participants who shared at least three scores.

Cognitive, IEQ and wellbeing data were obtained from 17 participants (10 male; 7 female). In addition to this, five participants (2 male; 3 female) only completed the diary part of the study, without sharing a sufficient number of game scores. The 22 participants were aged 26 to 54 (mean age= 38; standard deviation = 8.12).

Findings and limitations

The ‘High workspace choice’ group consisted of 13 participants, of which 11 completed the full study (diary and game); the ‘Low choice’ group was comprised of 9 participants, of which 6 completed the diary and shared scores. The majority of participants were in full-time employment, were active within four companies from the Real Estate or Financial sectors, and worked in highly skilled roles (72% Managers; 28% Non-managerial roles).

The study findings suggested possible relations between the participants' level of workspace choice, their cognitive learning abilities and wellbeing levels. As shown in Figure 1, participants' cognitive scores generally improved by playing the game repeatedly throughout the study, but the measure of improvement was slightly different between the two choice groups. 'High choice' participants' scores tended to improve more, while two-thirds of the 'Low choice' participants' score change was below the average 15% (Figure 1). Similarly, although wellbeing scores were in the moderate area for most of the participants, 'High choice' participants tended to have higher wellbeing scores; one third of the 'Low choice' participants' scores were in the low wellbeing area (Figure 2). Compared to the 'Low choice' group, 'High choice' participants tended to work in more varied settings during the five days and were more satisfied with the IEQ of those spaces.

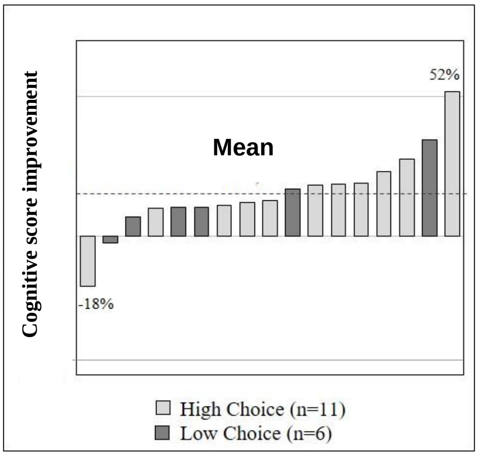

Figure 1. Workspace Choice pilot study (n=17) - Cognitive score

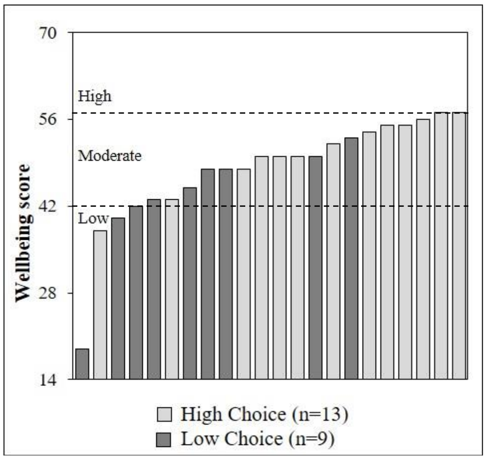

Figure 2. Workspace Choice pilot study (n=22) - Wellbeing

The main limitations of these findings are related to the problem of self-selection bias, which may have occurred as a result of the study design. This resulted in unequal sample sizes of the two choice groups. Also, many of the 'high choice' respondents were working in highly skilled roles (e.g. managers), which may influence both cognitive functioning and wellbeing. Future work controlling for these factors will be conducted to validate the preliminary findings of the study and explore the ‘workspace choice’ construct on a larger and more representative sample.

Conclusion

New ways of working - including part-time, flexi-time, activity-based working or homeworking - emphasize the role of individual choice regarding the use of physical workspaces. This paper reviewed major psychological theories discussing the mechanisms of choice, control and autonomy, which are generally associated with positive outcomes, but largely omit any role played by the built environment. Building on a gap of knowledge, the paper proposed that choice over when and where work if performed (‘Workspace choice’) is related to cognitive development and wellbeing. Preliminary insights from a small sample pilot study suggested higher degrees of workspace choice may be related to more cognitive improvement and higher levels of wellbeing. Future work on a larger sample is required to validate these insights.

Acknowledgments

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Appendix B.

Table B-1. Choice of work space and time: Descriptive statistics of (N=136; 408 observations)

		Choice of work space and time (averaged)	Choice of work space	Choice of work time
N	Valid	408	408	408
	Missing	49	49	49
Mean		4.25	4.35	4.15
Median		4.50	5.00	4.00
Mode		7.00	7.00	7.00
Std. Deviation		1.99	2.30	2.06
Minimum		1.00	1.00	1.00
Maximum		7.00	7.00	7.00
Percentiles	25	2.50	2.00	2.00
	50	4.50	5.00	4.00
	75	6.00	7.00	6.00

Table B-2. BAB and TCR cognitive test scores: Descriptive statistics (N=97)

Cognitive test	Statistic		Day 1 value	Day 2 value	Day 3 value
BAB	Mean		8364	11301	10258
	Std. Error of Mean		1072	1108	1054
	95% Confidence Interval for Mean	Lower Bound	6237	9102	8165
		Upper Bound	10492	13500	12350
	5% Trimmed Mean		6928	9938	8867
	Median		4360	7440	7525
	Variance		110221427	117782077	106648625
	Std. Deviation		10499	10853	10327
	Minimum		0	920	440
	Maximum		68630	58070	48180
	Range		68630	57150	47740
	Percentiles	25	2158	3893	3698
		50	4360	7440	7525
		75	10265	14345	12353
	Interquartile Range		8108	10453	8655
TCR	Mean		3368	5092	6251
	Std. Error of Mean		235	351	391
	95% Confidence Interval for Mean	Lower Bound	2901	4396	5475
		Upper Bound	3835	5789	7027
	5% Trimmed Mean		3262	4995	6175
	Median		3125	4400	5925
	Variance		5314585	11810280	14666894
	Std. Deviation		2305	3437	3830
	Minimum		200	100	450
	Maximum		8800	12950	13900
	Range		8600	12850	13450
	Percentiles	25	1113	1975	2550
		50	3125	4400	5925
		75	5088	7638	9588

Interquartile Range		3975	5663	7038

Table B-3. TUN and UNI cognitive test scores: Descriptive statistics (N=97)

Cognitive test	Statistic		Day 1 value	Day 2 value	Day 3 value
TUN	Mean		951	1576	1978
	Std. Error of Mean		64	87	96
	95% Confidence Interval for Mean	Lower Bound	824	1402	1787
		Upper Bound	1078	1749	2169
	5% Trimmed Mean		908	1543	1970
	Median		855	1477	2062
	Variance		390854	732222	888664
	Std. Deviation		625	856	943
	Minimum		30	70	60
	Maximum		3147	3893	4717
	Range		3117	3823	4657
	Percentiles	25	553	941	1335
		50	855	1477	2062
		75	1323	2093	2576
	Interquartile Range		770	1152	1241
UNI	Mean		3974	11556	12924
	Std. Error of Mean		221	541	540
	95% Confidence Interval for Mean	Lower Bound	3535	10483	11852
		Upper Bound	4413	12629	13996
	5% Trimmed Mean		3814	11635	12905
	Median		3700	11325	12965
	Variance		4694915	28048024	28001395
	Std. Deviation		2167	5296	5292
	Minimum		210	930	1460
	Maximum		14100	21680	25620
	Range		13890	20750	24160
	Percentiles	25	2560	8180	9200
		50	3700	11325	12965
		75	4988	15675	16025
	Interquartile Range		2428	7485	6825

Table B-4. Cognitive learning: Descriptive Statistics (N=98)

Cognitive learning (average percentage change of cognitive scores in day 3 minus day 1)		
N	Valid	98
Mean		213%
Median		153%
Mode		141%
Std. Deviation		206%
Minimum		2%
Maximum		1476%
Percentiles	25	104%
	50	153%
	75	256%

Table B-5. Wellbeing results: Descriptive Statistics (N=88)

Wellbeing scores		
N	Valid	88
Mean		22.19
Std. Error of Mean		0.31
Median		21.95
Std. Deviation		2.90
Skewness		1.17
Std. Error of Skewness		0.26
Kurtosis		3.44
Std. Error of Kurtosis		0.51
Minimum		16.88
Maximum		35.00
Percentiles	25	19.98
	50	21.95
	75	24.11

Figure B-1. Demographic information (N=129)

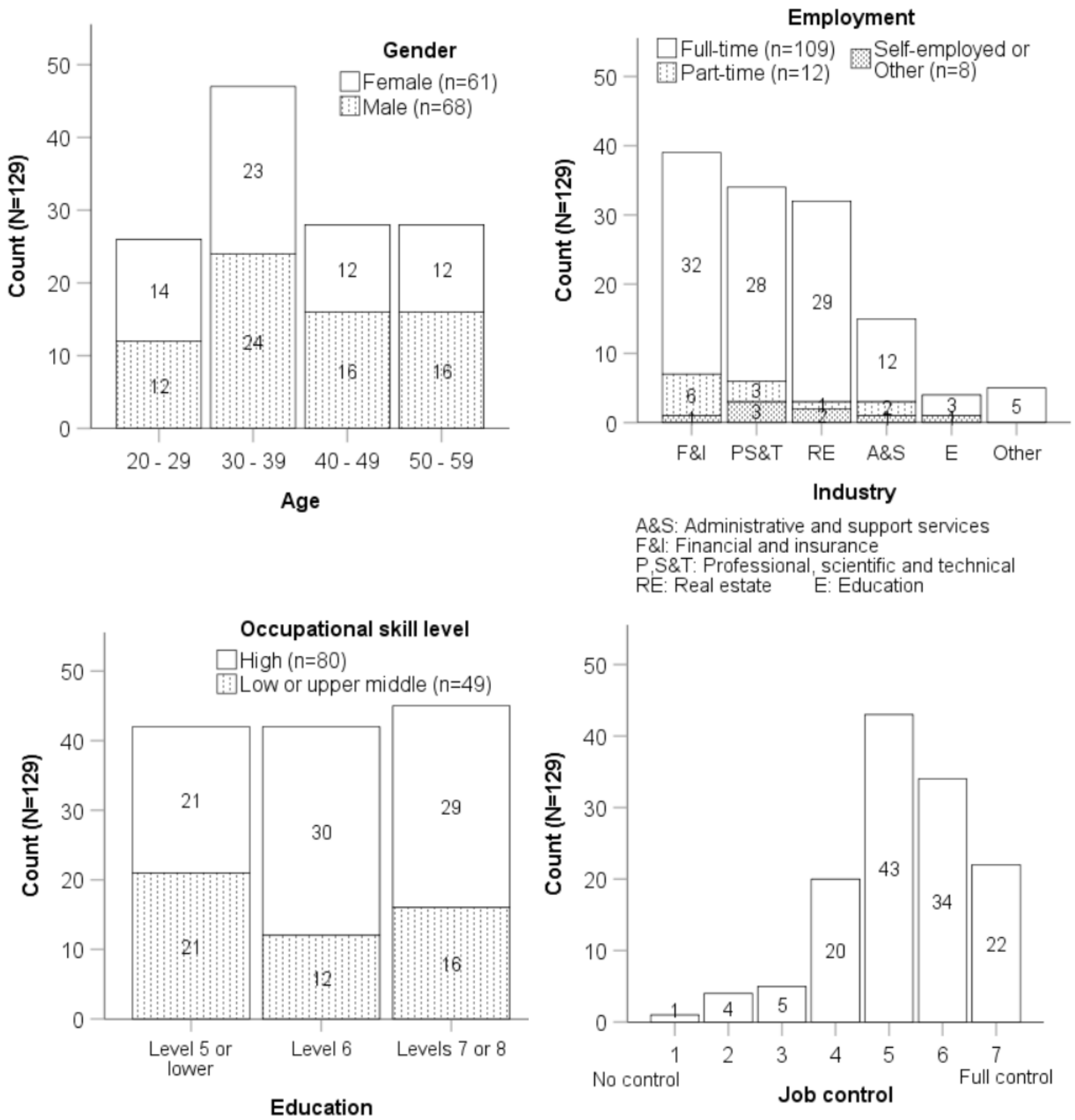


Figure B-2. The workspace: Location used (N=136; 408)

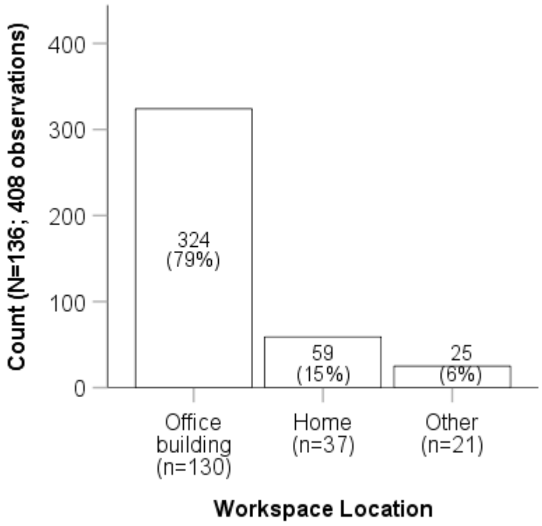


Figure B-3. The workspace: Typologies used in Office buildings and working from Home

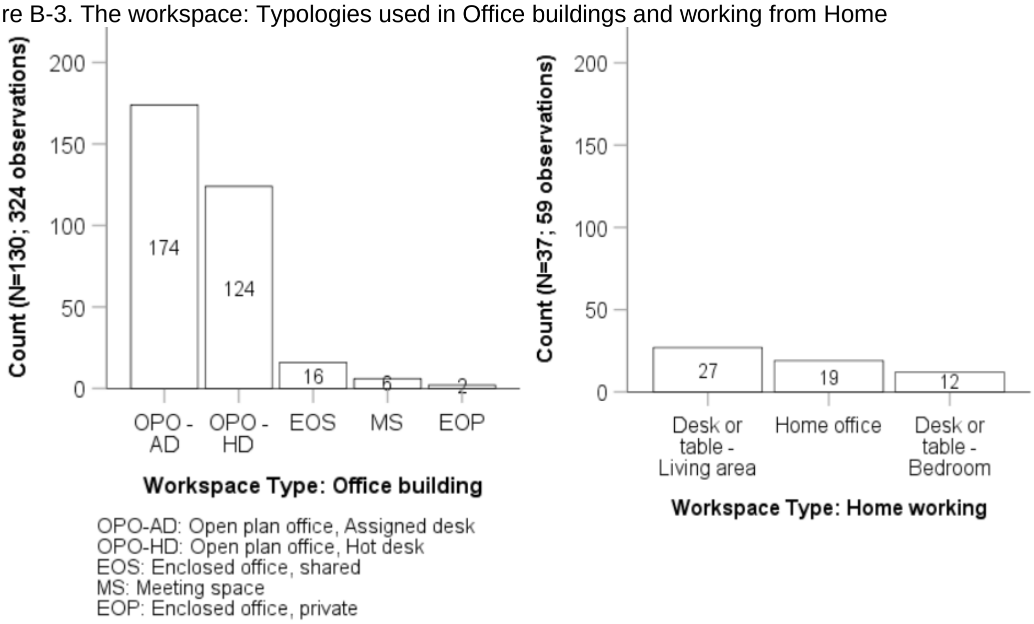
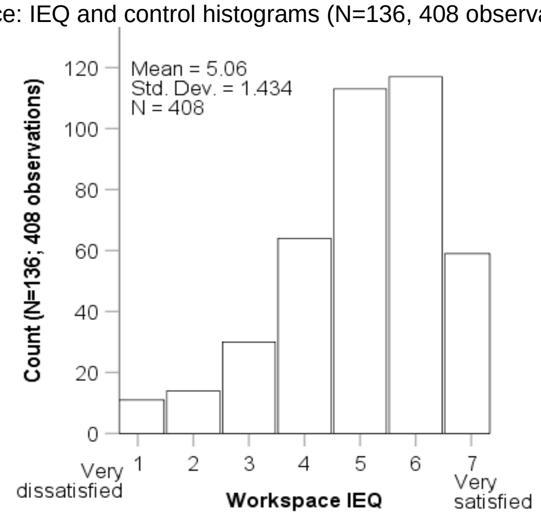


Table B-6. Workspace IEQ and Environmental control: Descriptive statistics (N=136; 408 observations)

		IEQ	Environmental control
N	Valid	408	408
	Missing	0	0
Mean		5.06	3.82
Median		5.00	4.00
Mode		6	2
Std. Deviation		1.434	2.046
Minimum		1	1
Maximum		7	7
Percentiles	25	4.00	2.00
	50	5.00	4.00
	75	6.00	6.00

Figure B-4. The workspace: IEQ and control histograms (N=136, 408 observations)



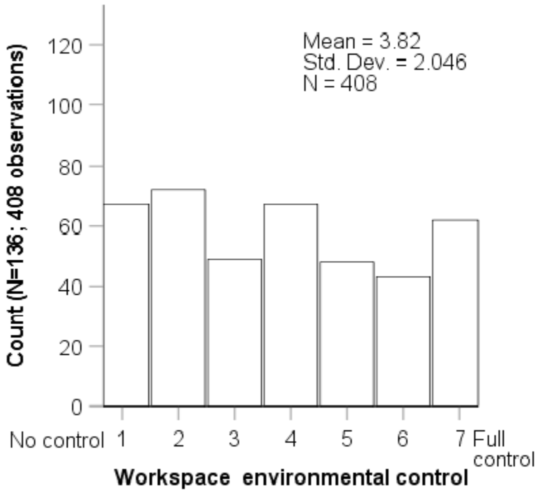


Table B-7.Choice of work space and time in the cognitive tests sample: Descriptive statistics (N=50; 150 observations)

		Choice of work space and time (averaged)	Choice of work space	Choice of work time
N	Valid	150	150	150
Mean		3.74	3.69	3.79
Median		3.75	3.00	4.00
Mode		2.00	1.00	3.00
Std. Deviation		1.90	2.28	1.90
Minimum		1.00	1.00	1.00
Maximum		7.00	7.00	7.00
Percentiles	25	2.00	1.00	2.00
	50	3.75	3.00	4.00
	75	5.13	6.00	5.00

Figure B-5. Workspace locations in the cognitive tests sample (N=50; 150 observations)

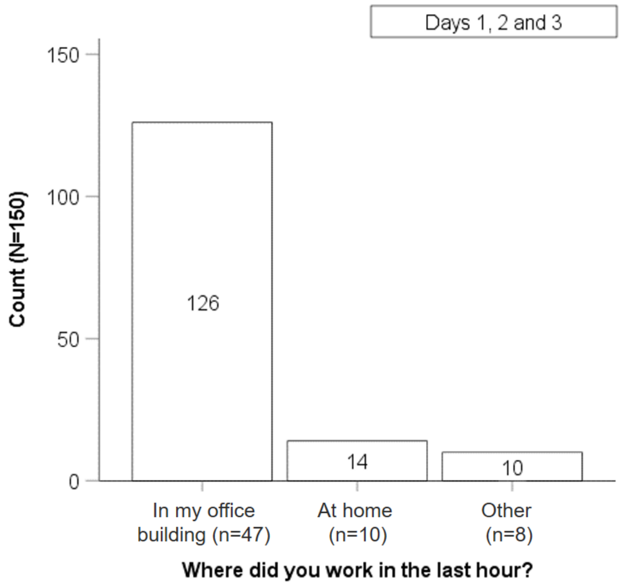
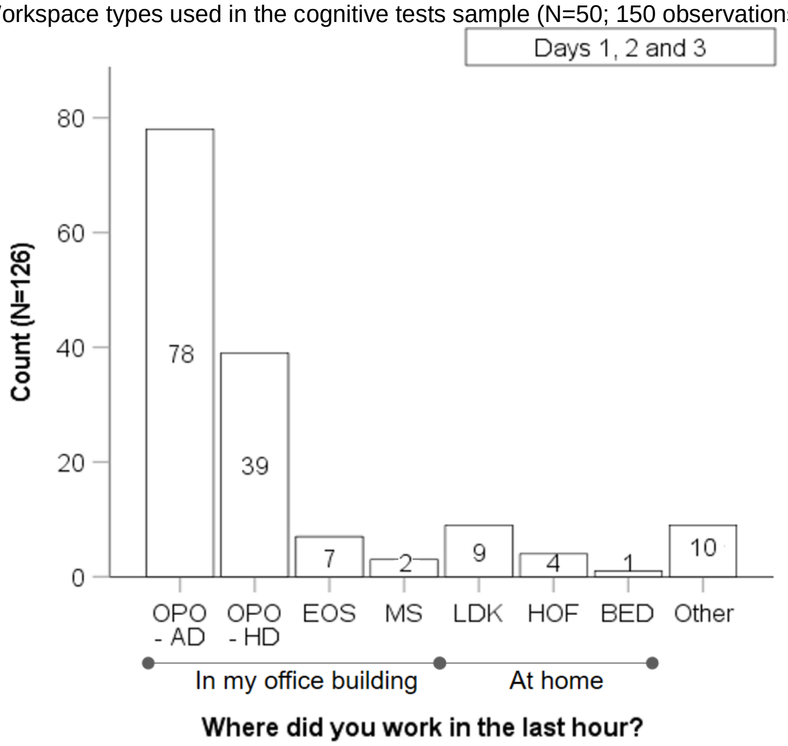


Figure B-6. Workspace types used in the cognitive tests sample (N=50; 150 observations)



OPO-AD: Open plan office - 8 or more people - Desk / workspace always assigned to me
OPO-HD: Open plan office - 8 or more people - Desk / workspace NOT assigned to me
EOS: Enclosed office - Shared with 1 to 7 colleagues
MS: Meeting space
LDK: Desk or table in the Living / Dining / Kitchen area
HOF: In a designated, enclosed workspace / Home office
BED: Desk or table in my bedroom

Figure B-7. Workspace IEQ in in the cognitive tests sample (N=50; 150 observations)

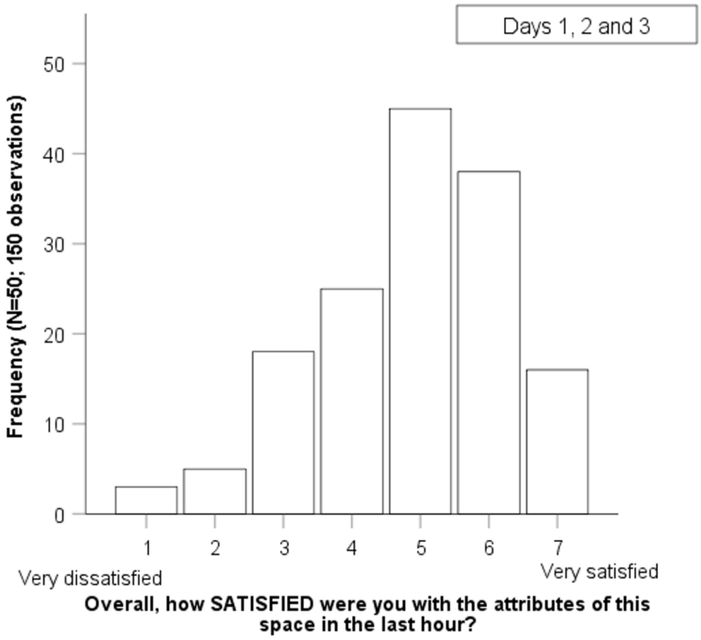


Figure B-8. Workspace control of attributes in the cognitive tests sample (N=50; 150 observations)

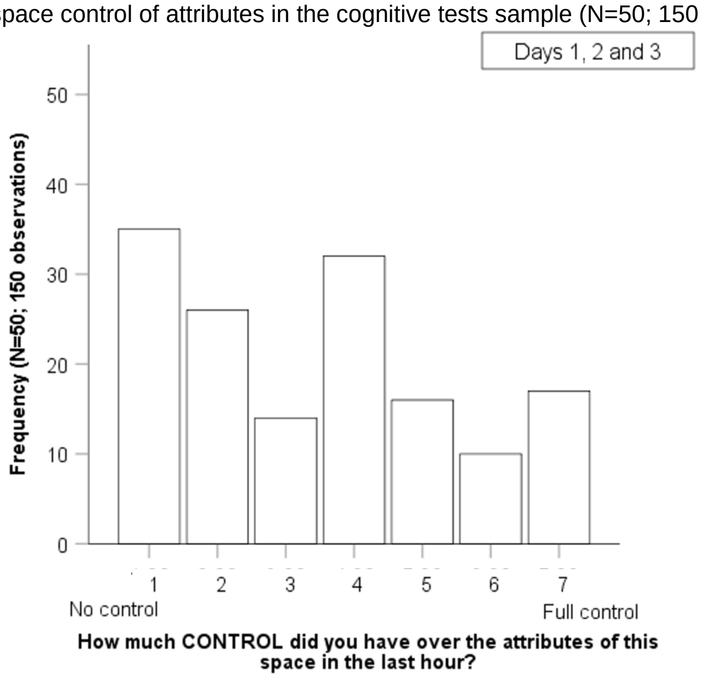


Table B-8. Workspace IEQ and control of attributes by Type (N=50; 150 observations)

Workspace type		Workspace IEQ	Control of workspace attributes
OPO - Assigned Desk	Mean	4.78	3.08
	N	78	78
	Std. Deviation	1.38	2.02
OPO - Hot Desk	Mean	5.13	3.90
	N	39	39
	Std. Deviation	1.15	1.65
Enclosed office, shared	Mean	4.43	3.29
	N	7	7
	Std. Deviation	1.40	1.60
Meeting space	Mean	5.33	2.33
	N	2	2
	Std. Deviation	1.15	1.53
Desk/table in Livingroom/Kitchen	Mean	5.00	5.33
	N	9	9
	Std. Deviation	1.66	1.73
Home office	Mean	6.50	6.25
	N	4	4
	Std. Deviation	0.58	0.96
Desk/table in Bedroom	Mean	4.00	6.00
	N	1	1
	Std. Deviation		
Other	Mean	4.11	1.67
	N	10	10
	Std. Deviation	2.03	1.12
Total	Mean	4.88	3.44
	N	150	150
	Std. Deviation	1.39	2.00

Figure B-9. Workspace IEQ in day 3 (N=50)

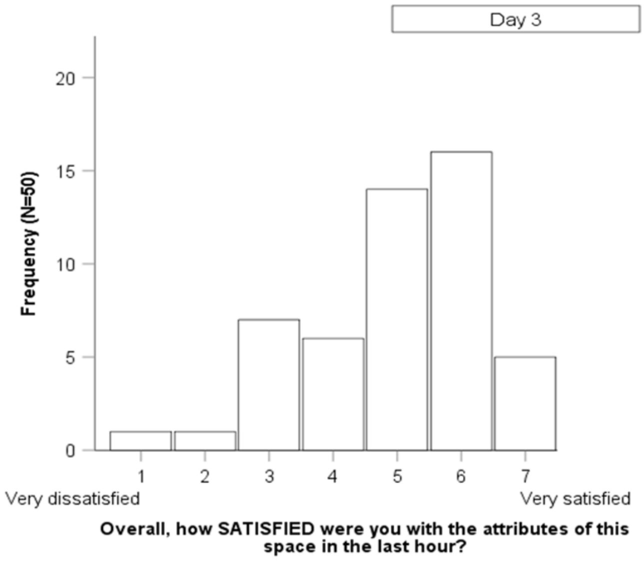


Figure B-10. Control of workspace attributes in day 3 (N=50)

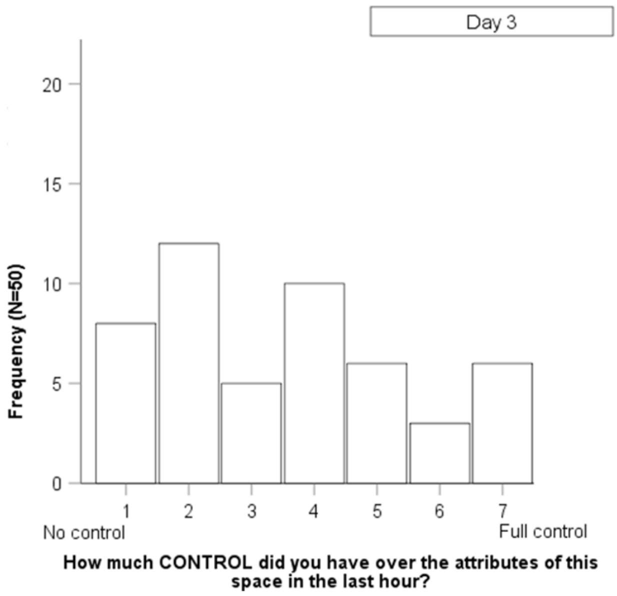


Figure B-11. Cognitive learning, Choice of work space and time and workspace Location in day 3 (N=50)

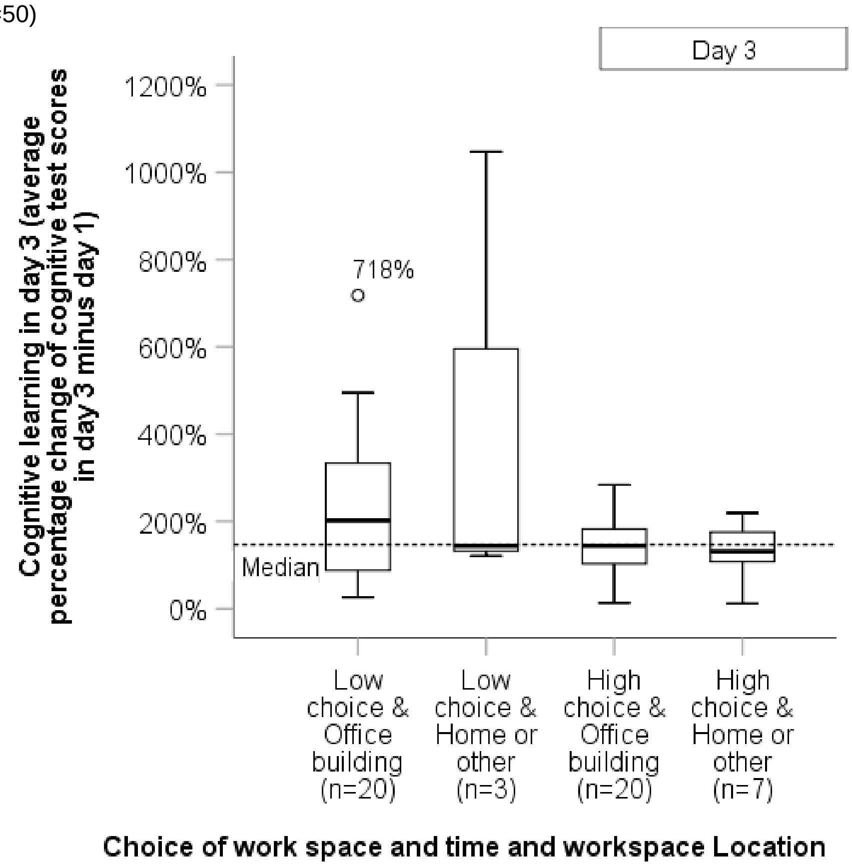


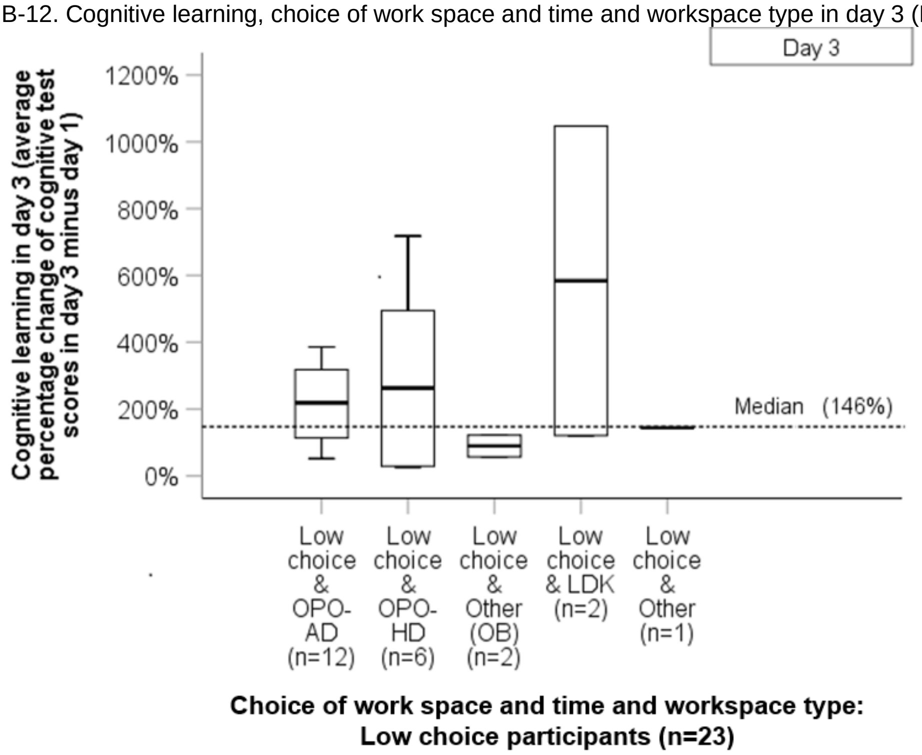
Table B-9. Specific workspace IEQ attributes in day 3: Descriptive statistics (N=35)

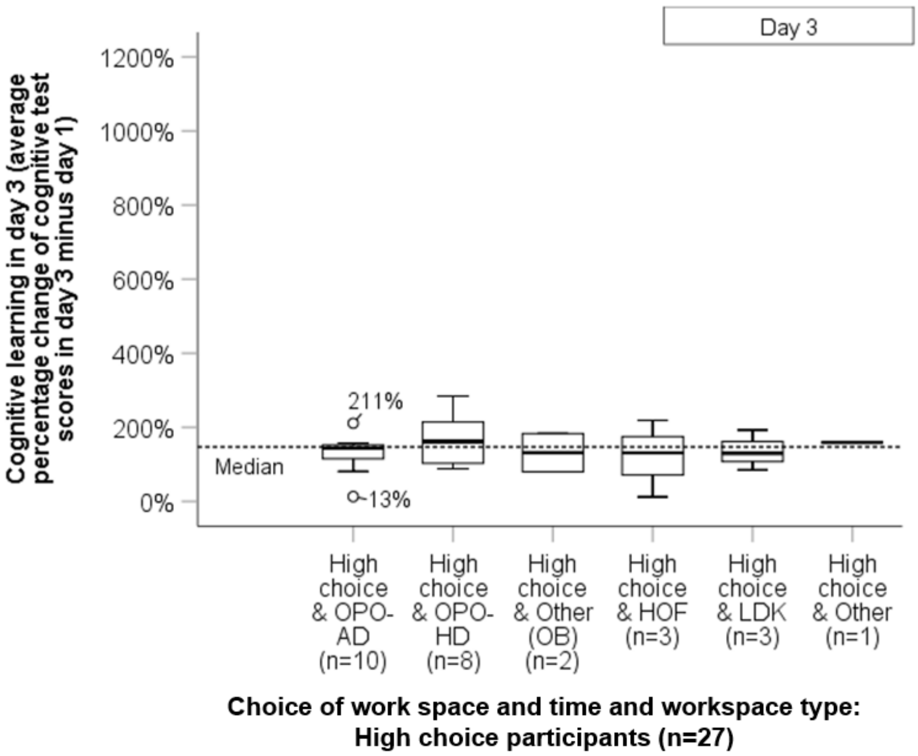
		TE	AQ	NL	AL	NO	UF	WT	DA	PR
N	Valid	35	35	35	35	35	35	35	35	35
Mean		4.71	4.40	4.63	4.23	4.00	4.69	4.26	3.91	3.31
Median		5.00	4.00	5.00	4.00	4.00	5.00	4.00	4.00	3.00
Mode		6.00	5.00	7.00	4.00	4.00	5.00[a]	3.00[a]	4.00	2.00
Std. Deviation		1.56	1.44	1.90	1.17	1.48	1.51	1.84	1.54	1.55
Minimum		2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maximum		7.00	7.00	7.00	6.00	7.00	7.00	7.00	7.00	7.00
Percentiles	25	4.00	3.00	3.00	4.00	3.00	4.00	3.00	3.00	2.00
	50	5.00	4.00	5.00	4.00	4.00	5.00	4.00	4.00	3.00
	75	6.00	5.00	6.00	5.00	5.00	6.00	6.00	5.00	4.00

a. Multiple modes exist. The smallest value is shown

Acronyms: TE: Temperature; AQ: Air quality; NL: Natural light; AL: Artificial light; NO: Noise; UF: Usability of furniture; WT: WiFi, IT, and work technologies; DA: Design and aesthetics; PR: Privacy.

Figure B-12. Cognitive learning, choice of work space and time and workspace type in day 3 (N=50)





OPO-AD: Open plan office - 8 or more people - Desk / workspace always assigned to me
OPO-AD: Open plan office - 8 or more people - Desk / workspace NOT assigned to me
LDK: Desk or table in the Living / Dining / Kitchen area
HOF: In a designated, enclosed workspace / Home office
BED: Desk or table in my bedroom

Table B-10. Cognitive learning and specific attributes of day 3 workspace IEQ: Nonparametric 1-tailed correlations (Spearman's rho)

			Cognitive learning in day 3	TE	AQ	NL	AL	NO	UF	WT	DA	PR
Spearman's rho	Cognitive learning in day 3	Correlation	1.000	-0.134	-0.383*	-0.392**	-0.299*	-0.155	-0.072	-0.326*	-0.130	-0.222
		Sig.		0.221	0.012	0.010	0.040	0.187	0.341	0.028	0.229	0.100
		N	35	35	35	35	35	35	35	35	35	35
	TE	Correlation		1.000	0.464**	0.212	0.185	0.503**	0.262	0.153	0.203	0.310*
		Sig.			0.002	0.111	0.144	0.001	0.064	0.189	0.121	0.035
		N		35	35	35	35	35	35	35	35	35
	AQ	Correlation			1.000	0.319*	0.164	0.241	0.082	0.207	0.180	0.389*
		Sig.				0.031	0.173	0.081	0.319	0.117	0.151	0.010
		N			35	35	35	35	35	35	35	35
	NL	Correlation				1.000	0.337*	0.247	0.431**	0.057	0.249	0.558**
		Sig.					0.024	0.076	0.005	0.373	0.075	0.000
		N				35	35	35	35	35	35	35
	AL	Correlation					1.000	0.162	-0.032	-0.058	0.062	0.169
		Sig.						0.176	0.427	0.371	0.363	0.166
		N					35	35	35	35	35	35
	NO	Correlation						1.000	0.497**	0.334*	0.143	0.427**
		Sig.							0.001	0.025	0.206	0.005
		N						35	35	35	35	35
	UF	Correlation							1.000	0.415**	0.546**	0.364*
		Sig.								0.007	0.000	0.016
		N							35	35	35	35
	WT	Correlation								1.000	0.396**	0.187
		Sig.									0.009	0.141
		N								35	35	35
	DA	Correlation									1.000	0.280
		Sig.										0.052
		N									35	35
	PR	Correlation										1.000
		Sig.										
		N										35

*. Correlation is significant at the 0.05 level (1-tailed).

**. Correlation is significant at the 0.01 level (1-tailed).

Acronyms: TE: Temperature; AQ: Air quality; NL: Natural light; AL: Artificial light; NO: Noise; UF: Usability of furniture; WT: WiFi, IT, and work technologies; DA: Designs and aesthetics; PR: Privacy.