UNIVERSITY OF LONDON THESIS

Degree Mphil   Year 2005   Name of Author COLLINS, J. M.

Is synaesthesia associated with any cognitive impairments?

An examination of numerical processing.

James Collins

MPhil Psychology

University College London

ABSTRACT

Synaesthesia is the involuntary experience of sensations, normally associated with one modality through another. It is thought to have a biological and genetic origin and other researchers have suggested that it could result in an uneven profile of cognitive strengths and weaknesses. The aim of this study was to identify potential deficiencies in arithmetical abilities and right-left discrimination between synaesthetes and matched control subjects. The hypothesis, based on the literature, suggested that synaesthetes would demonstrate impaired mathematical abilities and show signs of right-left confusability. A questionnaire and an array of objective tests were carried out to test this hypothesis. The subjective data reflects the literature, with significantly more synaesthetes reporting arithmetic problems and right-left confusion. The objective data, however, reveals no significant difference between synaesthetes and controls for basic arithmetic and right-left distinction tasks. These objective tests consisted of several response time measures of arithmetic, subitization, and left-right judgments. It is concluded that these problems are not a ubiquitous feature of synaesthesia, although they may be present in a subset of synaesthetes. Another line of evidence is presented that demonstrates a higher than expected occurrence of visuo-spatial mental number forms amongst our synaesthetic population. The role of spatial numerical processing is discussed as a possible explanation for the discrepancy between subjective and objective analyses; whilst numerical ability is not affected on a global level, numerical processing may be constrained by synaesthete's mental number forms, which are often complex and convoluted. The implications of this study are discussed in light of normal models of numerical processing.

ACKNOWLEDGEMENTS

A big thank you to my wonderful parents for their endless care and support; I am so lucky! I would like to thank my supervisor for his guidance and patience! Thanks also to the synaesthesia research group at Melbourne University for access to their pool of synaesthetes, without which this research would not have been possible, and for being so hospitable on my visit.

TABLE OF CONTENTS

FIGURES

TABLES

1 LITERATURE REVIEW AND OVERVIEW OF PRESENT STUDY

1.1 WHAT IS SYNAESTHESIA?

Synaesthesia can be described as a union of the senses where stimulation of one sensory modality gives rise to an extra perceptual experience, often in a completely different sensory modality. Synaesthesia is very heterogeneous; people's experiences include 'hearing' colours, 'tasting' shapes and 'feeling' sounds (Harrison & Baron-Cohen, 1997). The experience is not due to an attitude or strategy but a match between a stimulus, called an inducer, and a synaesthetic experience called a concurrent (Grossenbacher & Lovelace, 2001). Synaesthesia can be acquired through drug taking, e.g. LSD and mescaline (Hartman and Hollister, 1963) and various forms of sensory deprivation (Armel & Ramachandran, 1999). This study, however, will be concerned with the 'developmental' type. Synaesthetes report to have experienced these concurrents for as long as they can remember and are often surprised when they first discover that others do not share the same perception. When one synaesthete, studied by Dixon et al (2000), tried to explain multiplication to her younger sister she was surprised to find out that her mother and sister did not rely on looking at the 'colour' of the numbers to check whether the answer was right. Published estimates of the prevalence rates of synaesthesia range from 1 in 25,000 (Cytowic, 1993) to 1 in 2000 (Baron-Cohen, Burt, Smith-Laitten, Harrison & Bolton, 1996) although figures are considered to be conservative. A more reliable prevalence study using larger sample sizes and rigorous methodologies indicates the prevalence of synaesthesia is as high as 4.6% (Simner et al, in press).

Synaesthesia is an interesting topic that has important implications for cognitive neuroscience. Even though synaesthesia was recognised as an unusual perceptual phenomenon almost 300 years ago, by the philosopher John Locke (1704), relatively little is known about synaesthesia and many studies are anecdotal or introspective. The rise of cognitive psychology has begun to change this and a considerable resurgence in research has been seen over recent years. With higher prevalence than originally reported and a higher rate still amongst the members of families of synaesthetes, where prevalence is around 16% (Ward and Simner 2005), it seems that synaesthesia may have a genetic origin. The underlying research drive is to create an objective, scientific analysis of people's subjective experiences. Where a person's conscious experience differs from the normal population, it may be difficult to measure, but is hard to ignore.

1.2 HOW DO WE KNOW SYNAESTHESIA IS GENUINE?

Studies over the last 20 years have focussed almost solely on the matter of whether synaesthesia is a genuine phenomenon or not. Studies have aimed to prove to sceptics that synaesthesia may be a valuable source of information for a better understanding of normal perception and consciousness. 'Genuineness' of the synaesthetic experience has been supported by the use of imaging studies (Paulesu, et al. 1995, Cytowic and Wood, 1982), performance enhancement (Ramachandran & Hubbard, 2001) and performance interference (Wollen & Ruggerio, 1983; Mills, Boteler and Oliver, 1999). However, the technique most commonly used to lend weight to the argument that synaesthesia is genuine is consistency of the participant's experiences over time.

It is a well established trait of the synaesthetes reported in the literature, that a colour experience reported on the first presentation of the stimuli is the same as that reported on successive trials. For example Baron-Cohen (1987) reported consistency levels as high as 100% for his participant EP after a one-year interval, compared to 17% consistency for a control participant after just two weeks.

1.3 WHY IS THIS AN INTERESTING AREA OF RESEARCH?

The various perceptual experiences described, clearly differentiate synaesthetes from a normal population but it is worth considering whether there are any other features of synaesthesia that differ significantly from the normal population. The literature reveals no evidence of general mental or physical disability which tend to be observed with other genetic conditions affecting cognition such as Williams syndrome and Downs syndrome. If synaesthesia is free from such disabilities it represents an ideal model for the emerging field of cognitive genomics.

Whilst synaesthetes broadly demonstrate normal intelligence, some researchers have suggested that synaesthesia could result in an uneven profile of cognitive strengths and weaknesses (Cytowic, 1989). Many synaesthetes self-report problems with numeracy and left-right spatial ability (Cytowic, 1989). The latter two skills are known to reside in the left parietal lobe (Butterworth, 1999). If people with synaesthesia do have genuine cognitive weaknesses in these domains then it might suggest that the hypothetical synaesthesia gene(s) affects brain development in a number of ways, and not necessarily restricted to the perceptual domain. Problems with numbers and calculation (called dyscalculia) have substantial societal costs, and have a population prevalence of 5%.

This apparent uneven balance of cognitive strengths and weaknesses accompanying the unusual condition of synaesthesia will form the focus of this research project and the findings will inform a theoretical framework based upon normal numerical processing, representation and development.

1.4 UNEVEN PROFILE OF STRENGTHS AND WEAKNESSES?

Before analysing the potential atypical cognitive features of synaesthesia it is important to assess why synaesthetes may experience an uneven profile of strengths and weaknesses.

In general there are two claims as to how the existence of a cognitive imbalance amongst synaesthetes may be explained. The first claim is that they are simply co-morbid, with a common or related cause. For example, they may be two logically different outcomes arising from a single underlying mechanism (e.g. gene expression mediating brain development). The second, more interesting, claim is that synaesthesia actually causes numeracy and left-right problems. There are three ways in which the presence of synaesthesia *per se* may cause the observed problems; through interference of the concurrent experience; through reallocation of resources due to resource competition; or through dependence on a mental number form. These possible explanations are considered in more detail below.

1.4.1 Does the concurrent synaesthetic experience interfere with number processing?

When synaesthetes are asked to name the colour of a grapheme, their response is influenced by the presentation colour of the grapheme. If synaesthetes are presented with graphemes that have a presentation colour incongruent with the synaesthetes concurrent colour experience their colour- naming response times are significantly increased (Mattingley, Rich & Bradshaw 2001). This incongruency effect has been extended to demonstrate that numerical concepts alone can trigger synaesthetic colours and impact naming response times (Dixon et al. (2000)). Synaesthete 'C' was presented with simple arithmetical problems (e.g. 5+2) followed by a coloured patch (e.g. yellow or blue) that the synaesthete was required to name as quickly as possible. When the coloured patch was congruent with the synaesthetic colour induced by the solution (e.g. if the number 7 was yellow, and a yellow patch was presented) then naming speed was faster than when the colours were incongruent (e.g. if the number 7 is yellow, and a blue patch is presented). So, the outcome of the calculation was never physically presented, but the numerical concept still induced a synaesthetic response.

Perhaps the difficulty with number processing reported by synaesthetes is a result of incongruencies between the synaesthetic colours of the sum components and the synaesthetic colour induced by the solution. For example it may be difficult to provide the correct answer to 3 + 5 = 8 if the synaesthetic colours are unrelated e.g 'green' 3 + 'blue' 5 = 'red' 8. There is certainly anecdotal support for this theory, one synaesthete who participated in this study reported that they found it hard to understand how, say, a red number and an orange number can add to form a green number!

At a neural level this may be explained by greater connectivity between brain areas that subserve the relevant sensory and number processing modalities, creating interference among the representations; possibly owing to defective neuronal pruning early in life (Baron-Cohen et al., 1993). This hypothesis raises a challenge to the fundamental tenet of modularity, which deems that discrete units function independently.

1.4.2 Does competition for resources prevent normal number processing?

The presence of numerical difficulties amongst synaesthetes may be explained by competition for neural resources in key brain areas. For example synaesthesia may deplete the amount of computational resources available for numerical functioning, causing a reduction in normal performance. The phenomenon of resource competition is a familiar concept, one illustration of which comes from neuropsychological research. Patients with parietal lobe damage demonstrate 'extinction' whereby stimuli presented concurrently on the left and right side of the patient's visual field cannot both be processed, leaving the contralesional event undetected (Bender, 1952). This is interpreted to be a problem with selective attention, where simultaneous bilateral stimuli compete for limited attentional capacity, allowing only the ipsilesional stimulus to gain access to awareness (Ward, Goodrich & Driver, 1994). Evidence that may be even more relevant to a hypothesized competition for resources between synaesthesia and number processing is cross-modal extinction. Mattingley et. al demonstrated that extinction of a contralesional stimulus could be induced by the ipsilesional presentation of a stimulus in a different modality (Mattingley, Driver, Beschin & Robertson, 1997).

1.4.3 Does the presence of a visual number line interfere with number processing?

Synaesthetes often visualise number sequences as existing in a particular spatial arrangement called number forms or number lines. These can sometimes be highly convoluted (see Fig. 1.4). In some instances, the forms are reported to be on an inner screen (as in visual imagery) whereas other people report the form to exist in the space outside of their body. If synaesthetes experience numbers as part of a visual mental number line then there may be restrictions dependant on the specific spatial arrangement of the numbers that make it difficult to carry out certain calculations. Anecdotal evidence suggests this may be the case; one synaesthete with a particularly convoluted number form, when asked whether she experienced difficulty with maths, remarked "you try doing maths with a system like this".

The central aim of this study is to establish, using experimental paradigms, whether there is any evidence to support the claims that synaesthesia is accompanied by any deviations from typical cognition. An understanding of the reported patterns of cognitive weaknesses will be sought from the neuropsychological and developmental literature. Furthermore, potential aberrations experienced by synaesthetes will be used to inform existing models of normal number processing.

1.5 REPORTED PROBLEMS

Cytowic describes what he calls a synaesthesia 'personality', acknowledging that most synaesthetes are of normal intelligence but stating that there are commonly reported complaints that include, amongst others, a poor mathematical aptitude and a poor sense of direction. In a study of 42 synaesthetes 33 reported experiencing problems with arithmetic (Cytowic, 1989). A later study described two synaesthetes that Cytowic described as "frankly acalculic" and experiencing other features of Gerstmann syndrome, namely left-right confusability (Cytowic, 2002).

Though there are clearly subjective reports of cognitive weaknesses there have been no systematic experimental studies focusing on these potential problems amongst synaesthetes and whether Gerstmann syndrome is a suitable comparator. In order to determine whether synaesthetes can be equated to Gerstmann syndrome it is necessary to define the factors that comprise Gerstmann syndrome and to explore how these factors can be tested for in an objective fashion.

1.5.1 GERSTMANN SYNDROME

By analysing the similarities and differences between the profile of cognitive deficiencies observed amongst synaesthetes with a more well known syndrome it is possible to make inferences about the underlying nature of synaesthesia. As Gerstmann syndrome has been highlighted as a possible comparator in the literature (Cytowic, 1989; Ramachandran et al 2001) it is an obvious place to start. Gerstmann syndrome (Gerstmann, 1940) is observed after focal damage to the angular gyrus of the left parietal lobe and leads to a group of symptoms comprising acalculia, left-right confusion, finger agnosia and agraphia. Since the first observations made by Gerstmann in 1940, many cases manifesting this pattern of symptoms have been reported in the scientific literature (e.g. Ardila, Concha & Rosselli, 2000; Gold, Adair, Jacobs & Heilman, 1995; Jung, Yeo, Sibbitt, Ford, Hart & Brooks, 2001; Mayer et al., 1999; Suresh & Sebastian, 2000). There are some concerns over the categorisation of Gerstmann syndrome; rarely does it appear in a pure form, it is usually presented with either one of its main features missing or in association with other cognitive deficits (Ardila et al 2000; Wingard, Barrett, Crucian, Doty & Heilman, 2002). However examples of pure Gerstmann cases have been examined (Mayer et al, 1999) and there are clear similarities to the problems reported amongst synaesthetes. Gerstmann syndrome has also noted to be present in developmental form as well as after acquired brain damage (Kinsbourne, 1963).

1.5.2 ACALCULIA

The first of these cognitive difficulties, acalculia refers to the impairment of mathematical abilities after brain damage. Perhaps owing to the expansive nature of number and its extensive use in everyday life, the term acalculia has been applied to many different types of difficulty with numbers. Many single case studies have reported patients that experience number deficits that often affect specific realms of number processing such as naming, comparing, multiplying and subtracting – there is not an equal impairment across subjects (Chochon, Cohen, van de Moortele & Dehaene, 1999). The first systematic study of calculation disorders, in which Henschen (1925) examined patients with localized brain lesions, indicated that those with numerical processing deficiencies were most likely to have lesions in the area of the left angular gyrus (LAG). The LAG was purported by Henschen to be the cerebral substrate of arithmetic processing. Subsequently Critchley (1953) indicated that a variety of lesions could impact on calculation ability but only those that involved the left parietal lobe had any impact on the ability to understand number and number construction. A finer distinction was later made in which lesions within the left temporo-occipital lobe impaired number reading and writing; within the right parietal lobe impaired spatial organisation of numbers; and within the left retrolandic region impaired arithmetic computation (Hecaen, Angelegues &Houillier, 1961). So, it is generally accepted that, amongst adults, brain damage to the left parietal region disrupts arithmetic processing (Deloche & Seron, 1982).

The commonly reported acalculia amongst Gerstmann patients is a deficit in mental arithmetic, usually following a left inferior parietal lesion. Dehaene & Cohen (1997), presented a patient that was unable to compute 3 – 1 or 9 x 8 but was however, able to read the numbers aloud. A double dissociation for this pattern of results has been observed, whereby a patient was unable to read numbers aloud yet was able to compute arithmetic sums (Cipolotti & Butterworth, 1995).

Further double dissociations have been made between different arithmetic operations, most commonly subtraction and multiplication. There are many cases that demonstrate selective deficits in multiplication with spared performance on subtraction tasks (Dagenbach & McCloskey, 1992; McNeil & Warrington, 1994). Conversely, there are studies that demonstrate deficits in subtraction and spared multiplication (Delazer & Benke, 1997). Dehaene & Cohen (1997) presented a double dissociation case that differentiated parietal acalculia from subcortical acalculia. A patient with a left subcortical lesion was impaired on a rote memory task involving multiplication facts yet performed relatively well on subtraction and addition tasks. On the other hand, a patient with an inferior parietal lesion was unable to solve simple addition and subtraction sums, yet was able to retrieve rote multiplication facts (Dehaene & Cohen, 1997).

As Gerstmann syndrome is more commonly associated with damage to the inferior parietal region, one would expect poorer performance on a subtraction task, or the pattern of results associated with 'parietal acalculia'. If synaesthesia too is to fit the Gerstmann pattern then synaesthetes should demonstrate poorer performance for subtraction tasks.

An alternative source of information regarding number processing that may elucidate the underlying network of cognitive difficulties amongst synaesthetes is the genetic disorder literature. Although thorough investigations have not been made, numerical difficulties have been reported for many genetic disorders including Turner Syndrome (Rovet, 1994 and Butterworth, 1999), Fragile X syndrome (Mazzocco, 2001) and Williams Syndrome (Udwin et al 1996). As this study is concerned with developmental synaesthesia, developmental disorders may provide a more analogous comparator of arithmetic dysfunction. Whereas the neuropsychological evidence presented so far typically involves adult cases that have experienced some form of brain lesion there are many people with developmental disorders that experience a specific learning disability that affects the acquisition of normal arithmetic skills; this is referred to as developmental dyscalculia (DD). Prevalence of DD amongst children is considered to be as high as 6% (Shalev et al 2001) and, like the neuropsychological research, points towards impairments with the left parietal cortex as the locus of this difficulty (Isaacs, Edmonds, Lucas & Gadian, 2001).

Turner syndrome (TS) in particular bears similarities to the problems reported amongst synaesthetes. TS is a sporadic disorder amongst human females in which all or part of the X chromosome has been deleted (Rovet, 1994). Though the most striking elements of TS are the physical anomalies, short stature and ovarian dysgenesis, and problems with social adjustment there is also a neuropsychological profile of strengths and weaknesses. Whilst the verbal domain remains largely unaffected, there are usually deficiencies with visual-spatial impairments and DD, both of which have been raised as potential deficits in synaesthesia.

Although we know very little about the genetic basis of synaesthesia, it is interesting to note one theory associates it with the X-chromosome given the strong female:male bias and the pattern of inheritance documented so far (Baron-Cohen et al., 1996). A recent prevalence study however, does not reveal the female: male bias reported in other studies, pointing out that the bias may simply have arisen from a reporting bias; men are less likely to self-refer their atypical experiences (Simner et al, in press).

Evidence from acquired dyscalculia presents a clear distinction between processing of cardinal and ordinal numbers, that highlights the type of dyscalculia that tends to be observed in Gerstmann patients. Turconi & Seron (2002) presented a double dissociation between numbers in a cardinal context, that is numbers that refer to numerosity or quantity representation and ordinal number context, numbers that refer to sequence representation. Patient SE was unable to access the cardinal meaning of numbers, showing severe impairment on calculation tasks and application of arithmetic rules, whereas ordinal knowledge appeared to be preserved; SE successfully recited numbers, counted visual dot patterns and was able to report which number came next in a sequence. Patient CO showed a reverse pattern of behaviour, with preserved quantity processing and impaired order processing; CO was unable to report which number came next in a sequence and had difficulty counting dot patterns yet was able to understand and apply arithmetic rules. The type of impairment experienced by patient CO is more commonly experienced by Gerstmann patients as numbers have to be processed with reference to their relation to other numbers in a sequence, utilising a spatial comprehension of numbers.

1.5.3 LEFT/RIGHT DIFFICULTY

The other key cognitive difficulty observed as part of Gerstmann syndrome is left-right disorientation, usually defined by the inability to identify right and left in one's own body and in that of other people (Ardila, Concha & Rosselli, 2000; Wingard, Barrett, Crucian, Doty & Heilman, 2002). There is something special about the dimension left-right in the human brain, people find it more difficult to discriminate between left and right, than between up and down or front and back (Farrell, 1979; Ofte & Hugdahl, 2002).

Gerstmann himself reported that patients with his syndrome only experienced corporeal left-right problems, that is problems with comprehending space in relation to their own body. Since then however, many Gerstmann cases have been reported that demonstrate extracorporeal left-right difficulties (Alexander & Money, 1966). Combined with the other features described above, Gerstmann attempted to provide a theory to tie the symptoms together. He noted that right–left disorientation often occurred `with special reference to the hands and fingers' (p866, Gerstmann, 1957) the differentiation of fingers is necessary for writing, and fingers play an important role in the first arithmetic operations of children as well as in counting in primitive populations.

A more conservative view is that the symptoms correlate together because they tend to be in the same region rather than because of a causal relationship (e.g. there is little reason to believe that left-right confusion causes number problems or vice versa). However, there could still be a logical reason why development and evolution have located them nearby. The left parietal lobe contains a cross-modal spatial map of how the various parts of the body are laid out (a body schema), and this may serve as useful place-holders for counting as shown, for example, by the cross-cultural tendency to use body parts for counting and representing number names (Butterworth, 1999).

Gerstmann observed that the left right disorientation experienced by his patients had a tendency to reveal itself in relation to hands and fingers. In line with the central hypothesis that synaesthesia will reveal a similar pattern of cognitive weakness observed in Gerstmann syndrome, we would expect to observe poor performance on a task that required the participant to distinguish whether presentations of hands, in varying orientations, were images of a left hand or a right hand; this hypothesis will be tested directly. In addition, a task will be developed that tests synaesthetes ability to perform spatial judgements on an extracorporeal task.

If through objective analysis it becomes clear that synaesthetes do show the array of symptoms observed in Gerstmann syndrome we may infer that the same underlying pattern of differences occur at the neural level; this may facilitate guided further research utilising imaging techniques such as fMRI, improving our understanding of the underlying mechanisms involved in synaesthesia.

Having defined what synaesthesia is, the possible pattern of cognitive deficiencies that accompany synaesthesia, and the similarities with that of Gerstmann syndrome the following paragraphs will outline the current understanding of numerical and spatial processes and the most effective way to test for deficiencies of this kind. The Dehaene et al (1995) Triple-code model of numerical processing will be reviewed, highlighting areas of the brain that contribute to the difficulties reported amongst synaesthetes, to see whether there is any corroboration between the general literature and findings from Gerstmann syndrome studies. Particular attention will be paid to the involvement of the inferior parietal cortex, especially the angular gyrus in number processing and how this may be relevant to synaesthesia. Finally, mental number forms will be discussed. The parietal cortex has been suggested as an area for the processing of visual number forms and the prevalence of number forms is substantially higher amongst synaesthetes, identifying it as an important focus of discussion.

1.6 TRIPLE-CODE MODEL

Evidence has accumulated in favour of the Triple-Code Model (Dehaene, 1992) as the preferred model for understanding number processing (Fias, 2001). The triple code model differentiates three representations of number; verbal sequences of words, Arabic numerals and magnitude representation.

The verbal code allows for the comprehension and production of spoken numerals, based on a syntactic organisation of words, e.g. 'thirty-one'. The verbal code is reported to be the route for accessing semantic information about arithmetic facts, believed to be encoded in short verbal sentences such as 'seven times eight, fifty-six'. For the visual Arabic code, numbers are encoded as strings of digits on a visuo-spatial sketchpad (Chochon, 1999). Dehaene postulates that in the magnitude code numbers are represented in analogical quantities along an oriented number line or mental number line. The term 'mental number line' is applied to the cognitive representation of the meaning of numbers and was first postulated by Restle (1970). The two strongest pieces of evidence in support of an analogue representation are the observations that with the comparison of two numbers the difficulty increases as the distance between the two numbers increases (distance effect) and with a function of number size (size effect), with increasing difficulty for comparison of larger numbers (Moyer and Landauer (1967).

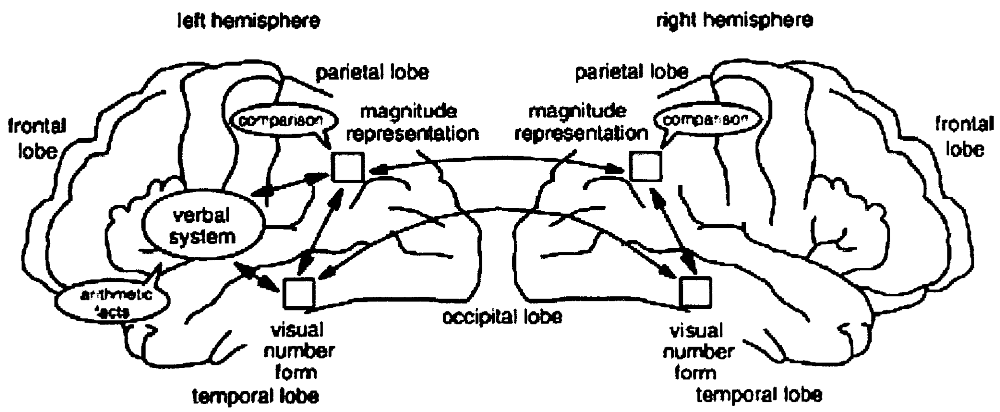

Fig. 1.1 The Triple Code Model (Dehaene, 1992); verbal, Arabic and magnitude representation

There are other models of number processing that need to be considered. McCloskey argues that magnitude is represented by decomposing numbers into bases – units, tens, hundreds and so on as abstract internal representations that can then be converted back into "Arabic numerals" (e.g. '36') or "verbal numerals" (e.g. "thirty-six) as a production output when required (McCloskey et al., 1985, McCloskey, 1992). This understanding of magnitude representation effectively means there are different mental number lines that deal separately with tens and units. This could be interesting because of the number forms reported by some synaesthetes that cluster in groups of 10; e.g. the numbers 1-10 appearing one above the other in a vertical line then 11 – 20 appearing in a similar vertical line positioned to the right of the previous vertical line, and so on. This raises the question as to whether the visual forms being seen by synaesthetes are in fact the abstract internal representation of magnitude that McCloskey argues for.

Further models have argued for a hybrid of the two models e.g. Nuerk, 2001. Nuerk is unable to deny the strength of the distance effect yet highlights the presence of the unit-decade-compatibility effect, which presents certain challenges for a single analogue magnitude representation for all single and double digit numbers. The compatibility effect leads to faster responses for determining which of two numbers is greater when both the tens and units, in a double digit comparison task, lead to the same result. For example when determining which of two numbers is greater, the presentation stimuli 42 and 57 are compatible stimuli as $4 < 5$ and $2 < 7$. This demonstrates that tens and units play a role in magnitude representation. Nuerk concludes that there may be both a magnitude number line representing all single and double digit numbers <u>and</u> separate bins for magnitude representations of tens and units within or in addition to the overall number line.

1.7 MENTAL NUMBER LINE ORIENTATION

It is suggested that the orientation of the mental number line is left to right, evidence for this can be observed in neglect patients. Earlier it was discussed that patients with unilateral neglect, following damage to the right parietal region show deficits when describing left-side stimuli and that the deficit extends to mental images (Bisiach & Luzzatti, 1978). When neglect patients are asked to determine the midpoint of a line by making a mark on a piece of paper, they miss the midpoint and tend to be biased to the right. Zorzi et al (2002) have demonstrated that neglect patients display the same pattern of results for a mental number line task. Patients are asked to determine, verbally, the midpoint between two numbers, for example stating that the midpoint of 1 - 5 is 3. Whilst control participants made few errors, neglect patients made many errors that were in keeping with the pattern of results seen for the line bisection task. Performance was significantly affected by the size of the number interval; with midpoint answers falling to the left of the real midpoint for the trials with the smallest intervals (e.g. 11 – 13) and right shifted errors for the longer intervals (e.g. 11 – 19). There is also a similar study by (Vuilleumier, Ortigue & Brugger, 2004).

1.7.1 SNARC EFFECT

Perhaps the most persuasive evidence for the orientation of the mental number line comes from the SNARC effect (Spatial-Numerical Association of Response Codes). When participants make parity (odd or even) judgements for numbers between 0 – 9 they are faster to respond to small numbers (<5) with their left hand and faster to respond to larger numbers (>5) with their right hand (Dehaene, Bossini, & Giraux, 1993, see Fig. 1.2). This was taken as evidence that reference was being made to a magnitude representation of number that is oriented from left to right; the left hand is able to respond to smaller numbers because they are closer to the left hand in mental space.

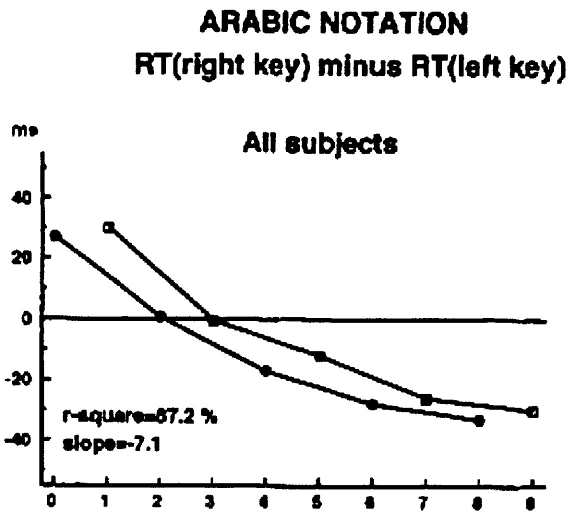

Fig. 1.2 SNARC effect, results from Dehaene et al (1993)

The key element of the Dehaene et al (1993) study is that the SNARC effect does not depend on the absolute position of the number but the relative magnitude of the number in the interval tested. In other words, relatively small numbers, that is 0 & 1 in the interval 0 - 5 and 4 & 5 in the interval 4 – 9, were responded to more quickly with the left hand than the right hand. On the other hand, relatively large numbers, that is 4 & 5 in the 0 – 5 interval and 8 & 9 in the 4 – 9 interval, are responded to more quickly with the right hand than the left hand.

Subsequently Dehaene et al. (1993) have demonstrated the robust nature of the SNARC effect by reporting the effect for both left and right handed participants and for participants with their hands crossed. However, the SNARC effect may be affected by reading direction; some Iranian born French citizens demonstrated a reversed SNARC effect, i.e. they were quicker to respond to larger numbers with their left hand and to smaller numbers with their right hand (Dehaene, 1997 Expt 7). Though the results were not resounding, a significant difference between an Iranian-French group and French group was largely due to the absence of any SNARC effect amongst many of the Iranian subjects, rather than a reversal in the direction of the SNARC effect though key individuals demonstrated a reverse SNARC effect. A closer look at the individual differences amongst Iranian subjects revealed that the extent of the difference from the French group was influenced by the length of time spent in the West; the longer the time spent in West the greater the similarity with the French group.

Dehaene et al (1993) do not attempt to account for the results of their SNARC effect using the triple code model. The triple code model does not differentiate, for example, magnitude and ordinal numbers. They do however, suggest that the SNARC effect may indicate that number processing draws upon visuospatial resources that are utilised for genuinely spatial tasks (Chochon, Cohen and Dehaene, 1999).

1.7.2 NUMBER FORMS

Whilst the mental number line is, for most of the general population, implicit, there are people that consciously report visualising their mental number line in a spatial pattern. (Seron, Pesenti, Noel, Deloche, & Cornet, 1992). The first reports of spatial configuration for concepts involving a serial order were made in the 19th century by Galton (1880b), who introduced the term 'number form' to describe them. From his studies, Galton estimated the prevalence of number forms to be 1 in 30 (3.3%) in men, and 1 in 15 (6.7%) in women (Galton, 1880a). In male schoolchildren, he estimated the prevalence to be as high as 1 in 4 (Galton, 1880; see also Peabody, 1915). Later studies have produced different prevalence estimates. Patrick (1893) reports a prevalence of one in six (16.7%) and Flournoy (1893) reports 1 in 9 (11.1%). Calkins (1895) reports number forms in 12% of women (sample size of 979), while Seron, et al. (1992) puts this figure at 13.7% (with 14.6% in males), from a sample size of 194, and Philips (1896-97) puts this figure at 7.7% (with 6.9% in males). Despite discrepancies in these estimates, all point to the fact that number forms are by no means exceptionally rare (see Fig. 1.3 for summary of the prevalence results).

Study	**N**	**Overall**	**Male**	**Female**
(Galton, 1880b)	-	5.0%	3.3%	6.7%
Patrick (1893)*	-	16.7%	-	-
Flournoy (1893)*	370	11.1%	-	-
Calkins (1895)	979	-	-	12.0%
Phillips (1896-97)	2009	7.3%	6.9%	7.7%
Seron, et al. (1992)	194	14.2%	14.6%	13.7%

Fig. 1.3 Prevalence estimates for mental number forms

The number forms appear automatically and are generally consistent over time. Galton noted that the forms in the schoolboys tended to consist of a linear left-to-right arrangement. Adults often had more convoluted forms with many twists and turns but which nevertheless also tended to progress from left-to-right; see Fig. 1.4 for examples of mental number forms recorded by Galton (1881, p97). Numerals (e.g. 5) rather than number names (e.g. "five") were visualised in all instances. Breaks or turns in the line frequently occurred at decade boundaries (10, 20, 30, etc.) and also at the number 12. The latter may reflect greater use of duodecimal systems during this period (12 pence in a shilling, 12 inches in a foot). Three out of 80 of his forms also appeared to have been influenced by clocks (i.e. the numbers from 1 to 12 arranged in a clockwise arc or circle). The forms were often 3D, existing in the space outside of the body.

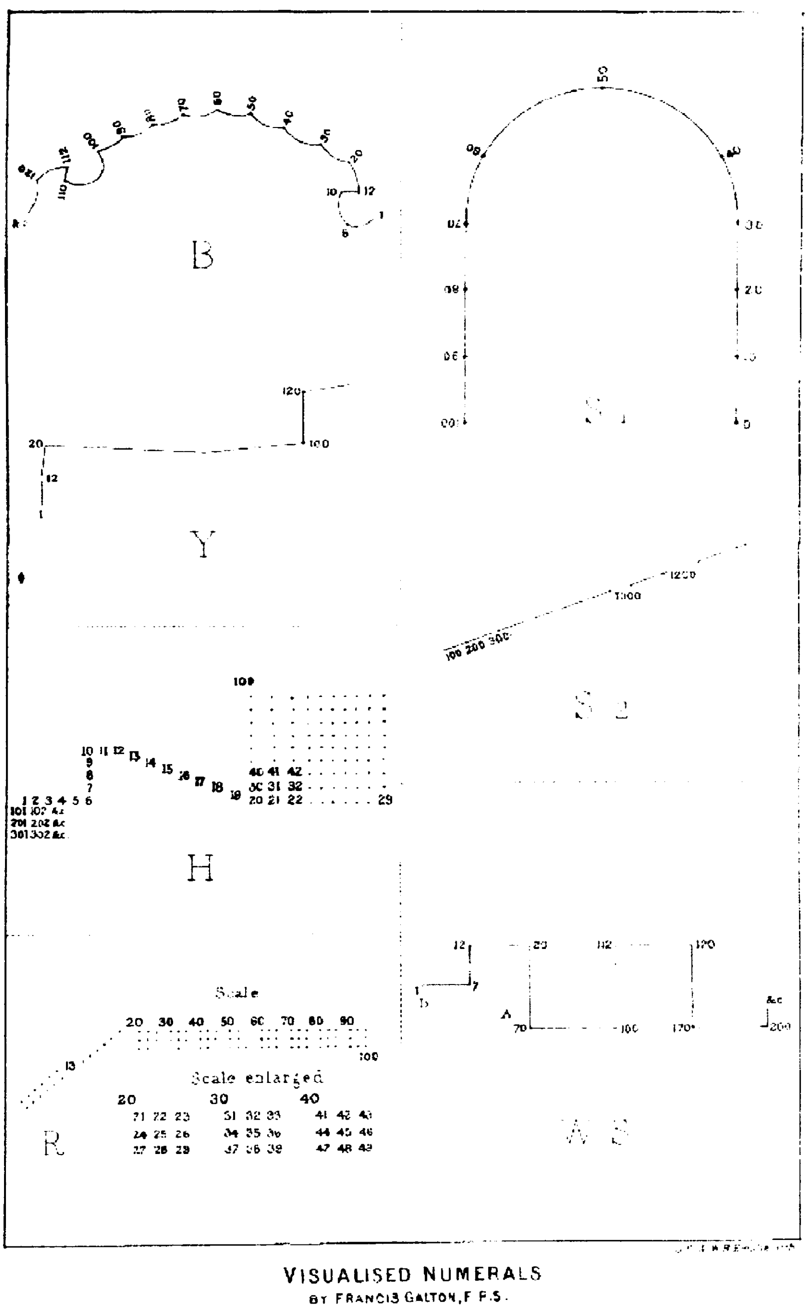

Fig. 1.4 Example mental number forms reported by Galton (1881, p97)

The fact that the majority of subjective reports indicate that number forms run from left to right also adds weight to the Dehaene model. There are however, reports of number forms that vary significantly from the left to right model purported by Dehaene. Many studies of synaesthesia have drawn attention to the additional presence of number forms in their subjects (e.g. Ginsberg, 1923; Wheeler, 1921; Collins, 1929; Odgaard, 1999; Baron-Cohen, 1987). A variety of number forms have been reported which in some cases run vertically, with small numbers at the bottom and larger numbers continuing upwards or even from right to left. Other number forms initially take on the appearance of a clock before straightening out to the right.

The relationship between number forms and reports of problems with number and calculation, from the questionnaire study, will be assessed. It is hypothesised that people with number forms experiencing problems with number/calculation will show poorer performance on the experimental tasks based on the prediction that number forms interact or interfere with number processing. As the prevalence of number forms appears to be greater amongst synaesthetes, this may explain why reports of dyscalculia are higher amongst the synaesthesia population.

1.8 NEURAL BASIS FOR NUMBER FORMS

Earlier it was argued that Gerstmann problems are the result of damage to the angular gyrus. What has become clear is that posterior-inferior regions of the parietal cortex, including the angular gyrus are most closely involved with visuospatial attention and we might therefore expect the angular gyrus to be involved with the spatial representation of numbers. Cerebral damage can selectively impair people's ability to visualise numbers. Spalding and Zangwill (1950) presented a brain-lesion case (AL) who reported loss of their mental number form following damage to the left parieto-occipital region. AL spontaneously reported that he "used to have a plan of numbers but then lost it" and later defined that it wasn't gone completely but was no longer distinct. After further recovery from the injury AL drew the number form, with some effort, and described how he used to utilise it during calculation. AL performed poorly when given a series of simple arithmetic sums, answering only 50% correctly, despite retaining a knowledge of arithmetical principles, attributing this to the loss of his number form. It is possible that AL was experiencing a more general form of primary dyscalculia but symptoms commonly associated with dyscalculia, such as dysgraphia, were very weak, if experienced at all.

It is argued that numbers are not represented by reference to exact numerical values but rather, abstracted from an underlying representation of magnitude that may be shared by both symbolic and nonsymbolic representations (Fias et al., 2003). Fias et al (2003) demonstrate that symbolic and nonsymbolic representations share similar patterns of brain activation in the IPS. The present study may provide support for the argument that the number form, explicitly visualised by the subject is actually the same as the underlying symbolic number line, automatically reverted to when processing numbers.

1.9 SUMMARY OF HYPOTHESES FOR THE PRESENT STUDY

This study will assess whether subjective reports of cognitive problems amongst synaesthetes are reflected in a wider population; it is hypothesised that a greater number of synaesthetes than controls will report experiencing problems with numbers and left/right abilities. It is further hypothesised that the presence of number forms will correlate with reports of poor arithmetic skills based on evidence that implicates the mental number line in number processing. The key cognitive impairments identified will then be tested at an objective level. It is predicted that a set of cognitive weaknesses will be identified in line with the Gerstmann pattern of impairments.

2 SELF-REPORTED DIFFICULTIES IN SYNAESTHESIA

2.1 INTRODUCTION

The focus of this chapter is to identify the extent of self reported arithmetic and left/right problems amongst a synaesthetic and control population. Previous reports of synaesthesia have raised the possibility of an uneven profile of cognitive strengths and weaknesses (Cytowic, 1989). Whilst Cytowic interviewed a large number of synaesthetes when conducting his research, his reports of arithmetic difficulty seemed to arise incidentally, rather than providing a structured investigation, focussing on such traits. One of the gaps in the synaesthesia literature that this study aims to address is the extent to which synaesthetes report difficulties with arithmetic and left / right dissociation and whether it is greater than amongst a control population.

This study focussed on the particular symptoms described above but the questions raised were included amongst a wide range of questions, as part of a large-scale questionnaire study devised to address multiple characteristics of synaesthesia. The other aspects of the question are not addressed here in full but a copy of the questionnaire is available in Appendix A.

Due to the assumed low prevalence of synaesthesia, the majority of studies published so far, have been single cases studies or group results collated over an extended period of time. The approach with this self report section of this study was to gain more accurate data about synaesthetes by increasing the sample size (n = > 100) to provide a more substantial generalisation to the synaesthesia population. There are inherent problems with this approach; the most challenging being the genuineness of the synaesthetes that complete the questionnaires. One of the early challenges of synaesthesia research was proving to sceptics that synaesthesia is a valid phenomenon. It is a well established trait of the synaesthetes reported in the literature that a colour experience reported on the first presentation of the stimuli is the same as that reported on successive trials. For example Baron-Cohen (1987) reported consistency levels as high as 100% for his participant EP after a one-year interval, compared to 17% consistency for a control participant after just two weeks. This consistency over time has become the key indicator of the 'genuineness' of synaesthesia and was utilised for the self report questionnaire in this study to ensure genuineness of synaesthetes.

In line with the described approach of testing genuineness, a consistency measure was developed, that was completed by all synaesthetes. Due to the logistical constraints of running consistency tests for all control participants, consistency data for control subjects was only gathered for a subset of controls, separate from the control group that answered the questionnaire.

Another question that needs to be addressed when assessing the results of the self reported questionnaire is whether synaesthetes tend to have a reporting bias when responding to questions about their cognitive experiences. For example, synaesthetes may report experiencing problems with arithmetic and left/right difficulties but if these problems are reported alongside a significant number of other atypical experiences then the dataset may be questionable. Whether or not synaesthetes actually have a specific pattern of cognitive strengths and weaknesses will be dealt with in the next chapter, using experimental paradigms. However, before further experimentation, a brief comparison of all the questions on the questionnaire will be made to see if synaesthetes have a tendency to report atypical experiences. One key comparator will be the synaesthetes response to a question included on literacy difficulties. In line with the previous reports, we would not expect synaesthetes to report problems with spelling or reading difficulty.

The expected pattern of results would be a higher number of synaesthetes than control participants reporting arithmetic and spatial difficulties whilst maintaining normal spelling and reading skills.

As well as clarifying whether anecdotal reports are true of a wider synaesthetic population, the questionnaire study will also be used to provide a set of variables that will be referred to when running objective analyses, later in the study. For example it is interesting to see whether those who report problems with arithmetic or report the presence of a mental number form experience difficulties with arithmetic in the experimental setting.

2.2 METHOD

A general questionnaire was completed by 117 synaesthetes and 270 control subjects. The mean age for the synaesthesia group was 42.2 years (ranging from 13 - 83 years) and the participants in the control group were taken from a typical undergraduate population.

The contents of the questionnaire covered a wide range of issues under investigation by the UCL Synaesthesia Research Group and as such not all of the questions were analysed as part of this study. Participants were given a description of synaesthesia and were asked to note any synaesthetic experiences that they thought they may have by drawing lines between a set of 'triggers' (numbers, letters, words, days, months, music, taste, smell, etc) and 'experiences' (colour, shapes, sounds, tastes, etc.) see Fig. 2.1 for an example. This was used to determine the type of synaesthesia experienced for the synaesthesia group and to ensure that no potential synaesthetes appeared in the control data.

SYNAESTHESIA QUESTIONNAIRE

Initials: ____________________ Age:____________ Sex: Male / Female

(1) Are you left or right handed?

(2) Please match the triggers on the left with experiences on the right. For instance, if you experience colours in response to numbers then draw a line in between 'numbers' (left) and 'colours' (on right), and so on. There is no need to draw lines between the same things (e.g. colours – colours) as this is assumed to be true of everyone.

TRIGGERS	EXPERIENCES
Letters of alphabet	Colours
English words	Shapes
Foreign words	Tastes
Peoples names	Smells
Addresses/places	Pains/touches
Numbers	Noises
Days of week	Patterns
Months of year	Flashes
Voices	Music
Pains/touches	Movements
Body postures	
Music (instrumental)	
Noises	
Smells	
Tastes	
Colours	
Shapes	
Patterns	

Fig. 2.1 Example cover sheet with lines indicating synaesthetic experiences

The questions of particular relevance to this study are shown in Fig. 2.2 below.

(13) Do you find that you often get left and right confused?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(14) Do you have (or have you ever had) problems with numbers and/or calculation?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(15) Do you have (or have you ever had) problems with reading and spelling?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(16) Do you think about the letters of the alphabet being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree
Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

(17) Do you think about numbers being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree
Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

(18) Do you think about days or months being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree
Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

Fig. 2.2 Questions of particular relevance from the questionnaire study

The questionnaire presented to control participants was a shortened version of the synaesthesia questionnaire but the questions under analysis in the present study were present in both versions of the questionnaire (see Appendix A for both versions of the questionnaire). One question, regarding visual forms, was presented differently in the two versions of the questionnaire, but both questions derive the same data. For clarification, the questions are shown below (Fig. 2.3a and 2.3b).

(12) Do you think about the letters of the alphabet (and/or days of the week/months of the year/numbers) as being arranged in a specific pattern in space?

Strongly disagree Disagree Neither agree nor disagree Agree
Strongly agree

If SO, Which ones? Letters Days Months Numbers Other?
____

Fig. 2.3a Control Questionnaire – One question covering different visual forms

(16) Do you think about the letters of the alphabet being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

(17) Do you think about numbers being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

(18) Do you think about days or months being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

Fig. 2.3b Synaesthesia Questionnaire – Three separate questions for different forms

The fundamental issues being assessed were a) do synaesthetes perceive themselves to experience perceptual and cognitive difficulties concerning left/ right distinction and mathematical abilities b) how many synaesthetes and control participants report experiencing visual mental forms for numbers, letters of the alphabet, days of the week or months of the year.

2.3 PARTICIPANTS

Synaesthetes were recruited through a participant recruitment website. A link was made between the BBC website (http://www.bbc.co.uk/radio4) and the UCL Synaesthesia Research Group website (www.syn.ucl.ac.uk). Following a two part series on synaesthesia aired on BBC Radio 4 ("Hearing Colours, Eating Sounds" 12th &

19th November 2002, 9.00 - 9.30 pm), participants logged onto the UCL website and registered an interest to participate in experimental research. Synaesthetes were initially selected on the basis of self selection (see the section below for further clarification of genuineness).

2.3.1 Synaesthesia group

The synaesthesia group comprised of two general types of synaesthete. 90% were grapheme-colour synaesthetes, who predominantly experience colours when viewing, listening to or thinking of a grapheme; for example when presented with the grapheme 'a' printed in black ink on a white background a grapheme-colour synaesthete may report they see a red letter. The other 10 % of the synaesthesia group were taste synaesthetes who perceive a taste experience in response to the visual or auditory presentation of certain words or letters. Whilst the two groups outlined represent the predominant synaesthetic experience, for many synaesthetes there are a large number of inducers and an equally wide array of concurrent experiences. Of the 18 'triggers' and 9 'experiences' presented, two of the synaesthetes drew lines between all possible pairings. The following two figures show the overall number of responses attributed to each inducer (Fig. 2.4) and the overall number of responses attributed to each concurrent experience (Fig. 2.5).

As Fig. 2.4 shows, the most commonly reported inducers are alpha-numeric stimuli; such as letters of the alphabet, numbers and words, particularly those with an ordinal nature, such as numbers, days of the week and months of the year.

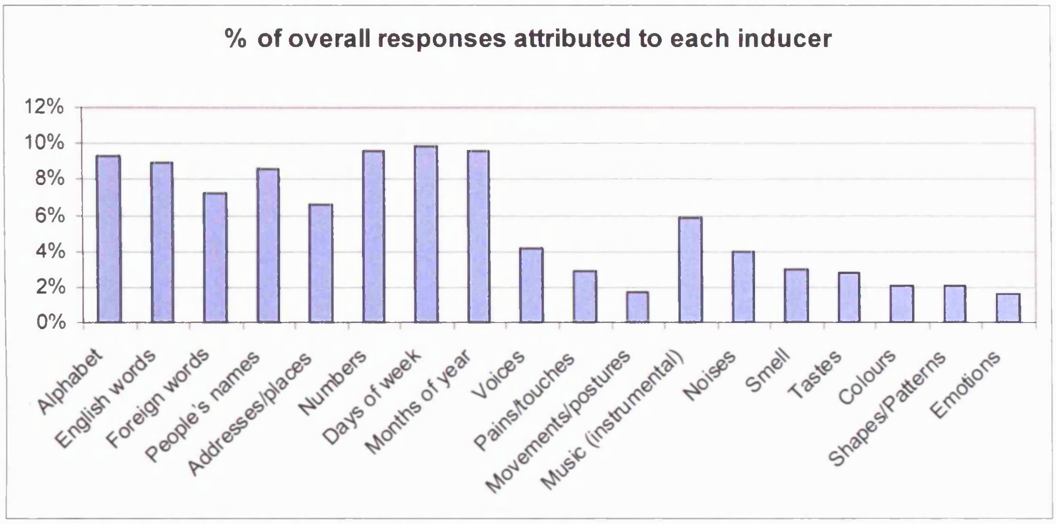

Fig. 2.4 Alpha-numeric and ordinal stimuli are more commonly reported as synaesthetic inducers

The most commonly reported concurrent experience is clearly colour (Fig. 2.5), though each of the other 8 experiences were reported to some extent. Note that there is a significantly higher number of synaesthetes reporting taste in the present study than in reports of other synaesthetic populations (Rich, 2005 and Day, 2004) as taste synaesthetes were specifically targeted for a separate research study.

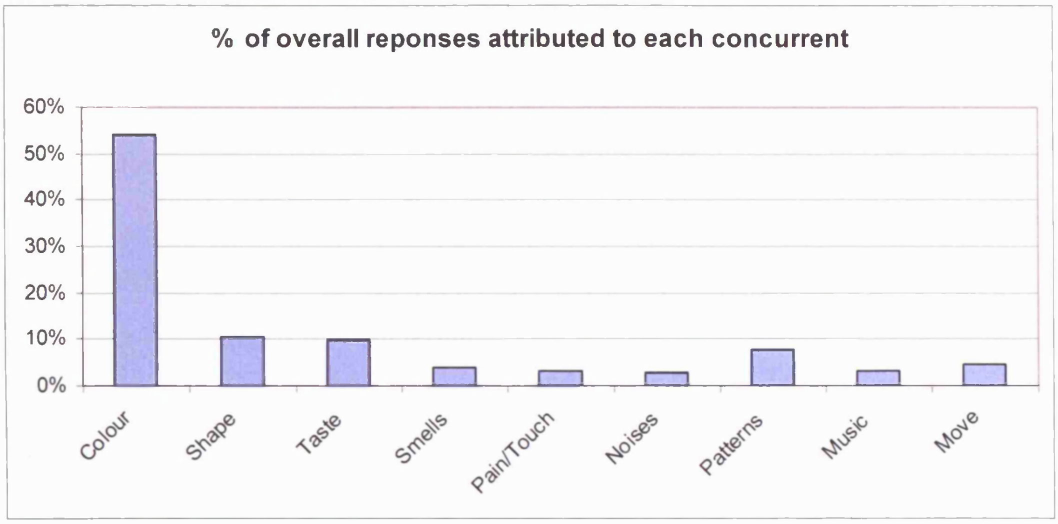

Fig. 2.5 The most commonly reported concurrent for all inducers is colour

2.3.2 Control group

The control group were all students at the University of Edinburgh with data being collated by a collaborating researcher. They were recruited through two sources; one sub-group consisted of psychology students who filled in a questionnaire as part of a course laboratory class and the other sub-group were drawn from other departments that had responded to an advert about participating in psycholinguistic experiments (with no specific mention made of synaesthesia or number forms).

From the Edinburgh sample, there were 111 participants reporting either synaesthetic or potentially synaesthetic experiences (78 female, 33 male). For the present study, we did not seek to verify these particular claims as it was our intention to collect a control sample without synaesthesia. As such, these participants were excluded. Thus, the control sample of non-synaesthetes consisted of 270 participants (196 female, 74 male).

It should be noted that there are some differences in age between the synaesthesia and control group, with the former being a heterogeneous group with large range in ages; and the latter a more homogeneous university population.

2.4 CONSISTENCY

Given the importance of consistency over time as a measure of genuineness of synaesthesia (Baron-Cohen, 1997), all synaesthetes were tested for the consistency of their synaesthetic reports. Participants were presented with a list of words, letters and digits and asked to "*describe succinctly and to the best of your ability the nature of your synaesthetic experience*" for each of the items on the list. A sample of 55 stimuli (including the letters of the alphabet, days of the week, months of the year and numbers 0 to 9) taken from the original list was presented to the same participants at an average of 5.1 months later (range of 1 – 18 months) and participants were asked to respond in the same way.

The synaesthetes were on average 90% consistent over time (ranging from 47% to 100%) resembling other reports of synaesthesia in the literature. Fig. 2.6 shows that there were very few synaesthetes with consistency below 70%. The lowest level of consistency was 47% (over an 8 month period), which is still higher than previous reports of consistency over time for control subjects (Baron-Cohen, 1997).

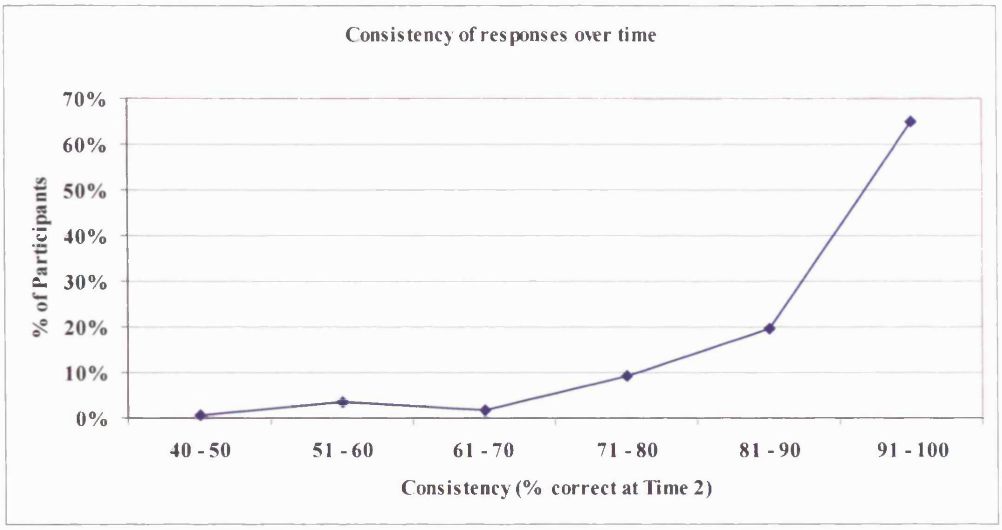

Fig. 2.6 Consistency of synaesthetic responses over time (avg. 5.1 months)

To ensure that consistency for the stimuli in the present is comparable to previous studies, and to justify the inclusion of all synaesthetes in the sample, a group of 65 control participants also completed the consistency experiment (note that the control group for the consistency comparison is different from the control group that completed the questionnaire study). The average consistency amongst controls was 36.6 % (ranging from 1.9% to 82.6%) after a much shorter time period of 2 weeks; substantially lower than the consistency for synaesthetes.

The high consistency amongst synaesthetes provides objective evidence that they are genuinely different from control participants engaged in just memory or imagery.

2.5 RESULTS

The questions of concern were answered using a five-point Likert scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree). According to the hypotheses there should be a difference in response to the number/calculation question compared to the reading/spelling question. The reading and spelling question was included to provide a comparison with the number / direction questions. In line with previous reports, it is predicted that synaesthetes will report problems with left-right confusion and mathematical problems but not report reading/spelling difficulties. As reading / spelling difficulties have not been highlighted before, this question may act as an indicator of reporting bias; if synaesthetes report reading / spelling difficulties, we may conclude that synaesthetes have a general reporting bias towards experiencing difficulties.

The five point scale of responses were collapsed into three groups, "agree", "neither" and "disagree" and analysed as a 3X2 Chi-square non-parametric test.

2.5.1 Left-right confusion

As predicted, a significantly higher number of synaesthetes reported left/right confusion than control participants, ($\chi^2(2)=10.17$, $P<.001$). There was also a strong gender difference particularly for the control group; 30 % of females reported problems with left / right confusion as compared to 8% of men. The responses provided are shown in Fig. 2.7 below.

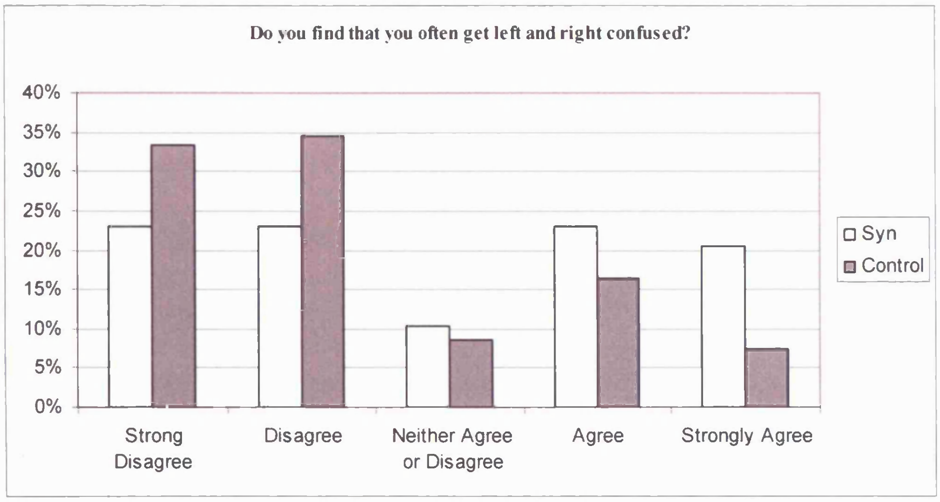

Fig. 2.7 Reports of left / right number confusion are higher amongst synaesthetes

2.5.2 Number and calculation

Higher numbers of synaesthetes reported problems with calculation than the control group, ($\chi^2(2)=17.17$, $P<.001$), which fits with the hypothesis based on previous qualitative reports that synaesthetes will report difficulty with numbers and calculation. Results are shown in Fig. 2.8.

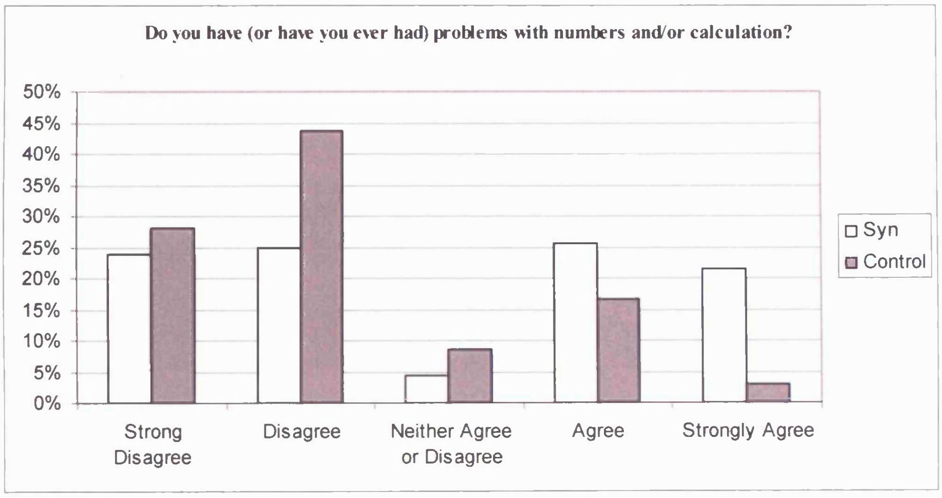

Fig. 2.8 Number of reports of number / calculation problems are higher amongst synaesthetes

2.5.3 Reading and spelling

There is no significant difference between synaesthetes and controls for the reading and spelling question, ($\chi^2(2)=4.5$, N.S.). This fits with the hypothesis that suggested synaesthetes would not report difficulty with reading and spelling as these reports have been absent in previous studies. There is also a trend for synaesthetes reporting "strongly disagree" for reading/spelling problems whereas controls are split between "disagree" and "strongly disagree" (Fig. 2.9). Other questions in the questionnaire that are unrelated to the current project also show that synaesthetes do not show a reporting bias; for example, there is no significant difference between synaesthetes and controls for the questions "Do you ever have the feeling that you have lived through this moment before (déjà vu)?" ($\chi^2(2)=1.25$, N.S.), "Does it ever feel that time has come to a stand still?" ($\chi^2(2)=2.83$, N.S.), and "Do you ever feel as if you were standing aside and watching yourself?" ($\chi^2(2)=2.72$, N.S.).

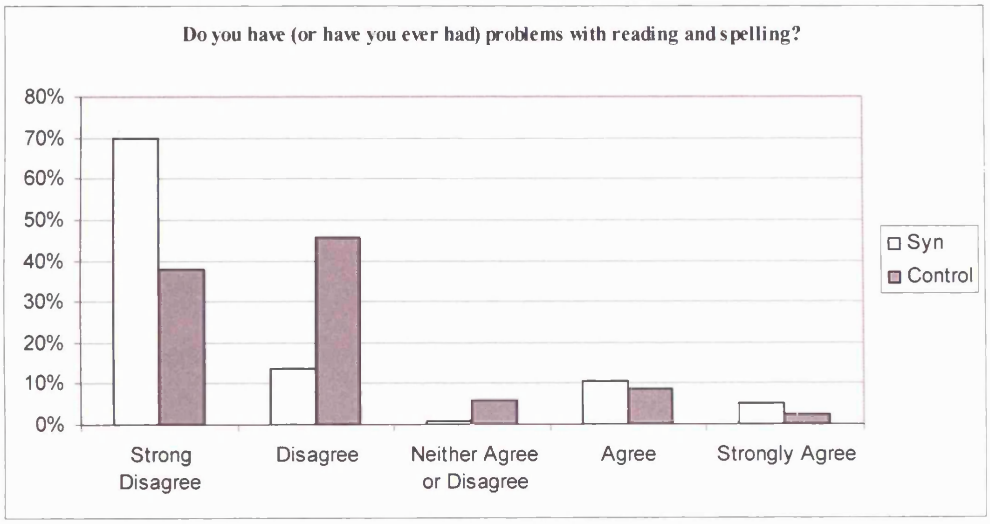

Fig. 2.9 No significant difference between groups in reports of reading / spelling problems

2.5.4 Visual mental forms

In line with previous reports a large proportion of the synaesthesia group reported mental number forms, 53% in total. Thirteen percent of the controls reported number forms. This lies within the prevalence range of 5 – 17% described in chapter 1. Contrary to the reports of Galton (1880), but similarly to the findings of Seron et al. (1992), we found that number forms were equally as common in men and women ($\chi^2(1)=0.87$, N.S.). There was however, a trend in the direction of being more common in women.

The relationship between number forms and reports of problems with number / calculation was also assessed. The results show a significant difference between groups, with those reporting number forms experiencing problems with number/calculation, ($\chi^2(1)=5.79$, P=.016). In line with the hypothesis, this suggests that number forms may interact or interfere with number processing. The higher percentage of reports with arithmetic problems amongst synaesthetes may be explained by the higher prevalence of number forms.

	Number problems	**No number problems**
Number Form present	**35** (40%)	**52** (60%)
No number form present	**73** (24%)	**227** (76%)

Table 2.1 Relationship between number forms and number / calculation problems

One reason why numbers may be amenable to this type of representation is that they are an ordered set. If it is the ordinal nature of numbers, rather than numerical size, that gives rise to a visuo-spatial format of representation then we might expect other types of ordinal sequences to be represented in this way (e.g., letters of the alphabet and units of time). Indeed, Gevers, Reynvoet and Fias (2003) have found a SNARC effect in the non-synaesthetic population for months and letters of the alphabet, with earlier months and letters being leftmost. The figures below show the occurrence of visuo-spatial forms for numerals, letters of the alphabet and time (days and/or months) for synaesthetes (Fig. 2.10) and controls (Fig. 2.11). First, we see that mental representations of letters and time are also commonly found in synaesthesia, the prevalence rates being 64% (controls=14%) and 67% (controls=19%), respectively. Second, it appears that that if a synaesthete has one type of form then there is a very strong tendency for them to also have at least one other type of form (as seen from the high overlap in the Venn diagram). The same holds true for the non-synaesthetes being simply that the phenomenon, overall, is less common in these latter groups. We might conclude, then, that visuo-spatial forms appear to be related to ordinal representations rather than numbers in particular.

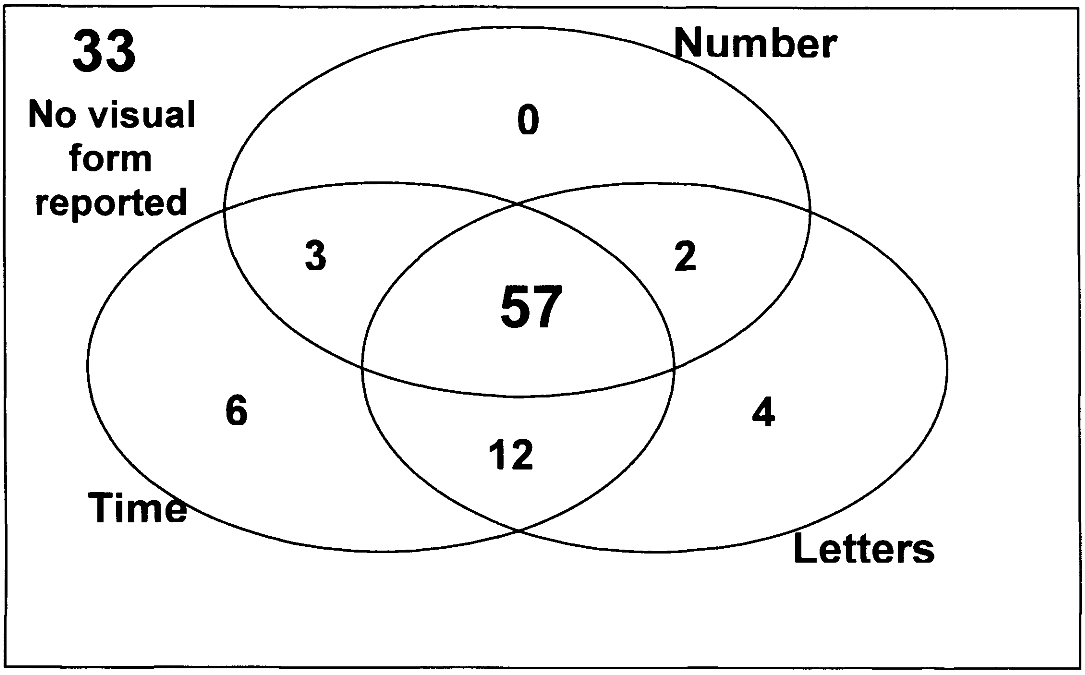

Fig. 2.10 Venn diagram showing the occurrence of visual forms for Synaesthetes

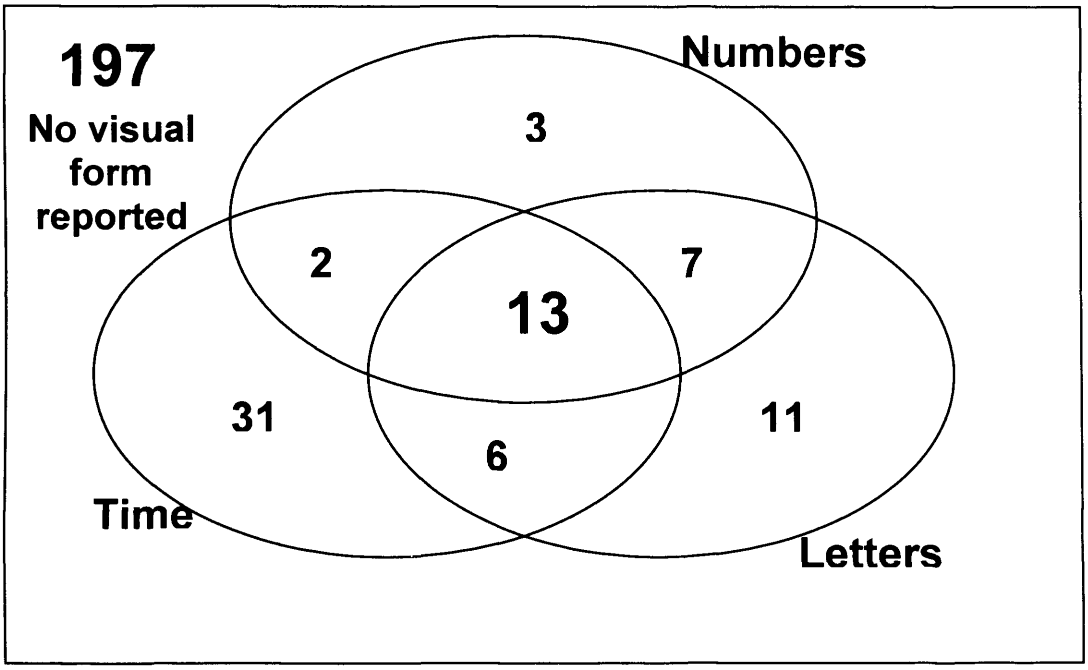

Fig. 2.11 Venn diagram showing the occurrence of visual forms for Controls

The general visuo-spatial characteristics of the number forms exhibited by the synaesthetes are shown in Table 2.2 with some examples drawn in Fig. 2.12. The forms were classified according to their overall direction (considering the digits 1-100) and the direction for the first 10 digits. In addition, the number of instances in which the form was continuous or discontinuous (i.e. whether there were breaks in the number line in which the line stops and restarts at another position in space) is shown. Numbers are also classified by whether they existed as a straight line or contained curves, bends or undulations. The most common was a straight line (61%), followed by continuous but not straight (23%) with the remainder reporting discontinuous forms, some of which were highly complex.

Direction	Synaesthetes (%)	
	Overall (1-100)	Initial (1 -10)
Left to right	70	63
Right to left	9	5
Bottom to top	11	18
Top to bottom	0	0
Circle	2	4
Other	9	11
	100%	100%

Table 2.2 Visuo-spatial characteristics of synaesthetes number forms

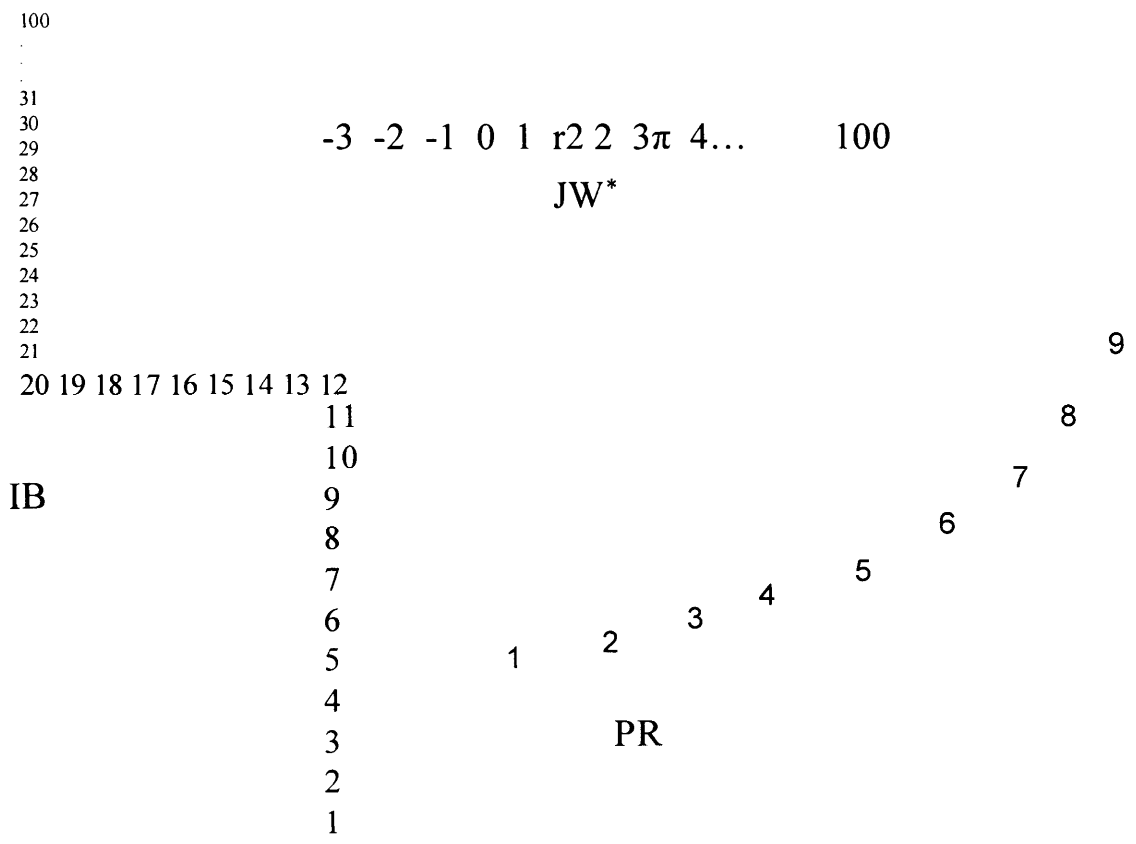

Fig. 2.12 Example number forms reported by synaesthetes in present study

* JW described having mathematical symbols that appeared at their appropriate location along her number line

2.6 CHAPTER DISCUSSION

In line with other reports of the synaesthetic population (Day, 2004; Rich, 2005 and Cytowic, 1989) the present study found that synaesthetes self report arithmetic and left/right problems, bolstering the claim that synaesthetes have an uneven profile of cognitive strengths and weaknesses.

The large sample size of synaesthetes involved in the self-report questionnaire allow us to make more substantial generalisations to the wider synaesthesia population than the single case studies that gave rise to the original claims. This study provides strong qualitative data and highlights clear areas for objective analysis, that will be presented in the following chapters.

One concern was that synaesthetes would demonstrate a reporting bias for being "different" on all questions asked. This was not the case as synaesthetes did not report experiencing difficulty with reading / spelling which suggests a blanket departure from the expected normal response was not adopted.

The self-report questionnaire indicates some correlation between number forms and problems with number and calculation; those experiencing number forms are more likely to report problems number problems than those that do not experience number forms. As more synaesthetes than controls experience number forms, perhaps reported problems with calculation are accounted for by the presence of number forms, or specific types of number forms. This correlation will be further examined through objective analysis in later chapters to see whether there is any causal relationship; does the presence of a number form actually interfere with normal calculation?

3 OBJECTIVE MEASURES OF DYSCALCULIA AND LEFT-RIGHT CONFUSION IN SYNAESTHETES

3.1 INTRODUCTION

The hypotheses for each of the experiments in this chapter will draw on the central hypothesis that synaesthetes have a set of cognitive strengths and weaknesses that are analogous with Gerstmann syndrome.

The commonly reported acalculia amongst Gerstmann patients is a deficit in mental arithmetic, usually following a left inferior parietal lesion. Dehaene & Cohen (1997), presented a patient that was unable to compute '3–1' or '9x8' but was however, able to read the numbers aloud. In line with these results, it is predicted that synaesthetes will demonstrate poorer performance for arithmetic than the control group. As described in chapter one there are many studies that present double dissociations between subtraction and multiplication. As Gerstmann syndrome is more commonly associated with damage to the inferior parietal region, one would expect poorer performance on a subtraction task. If synaesthesia too is to fit the Gerstmann pattern then synaesthetes should demonstrate poorer performance for subtraction tasks.

The other key cognitive difficulty observed as part of Gerstmann syndrome is left-right disorientation, usually defined by the inability to identify right and left in one's own body and in that of other people (Ardila, Concha & Rosselli, 2000; Wingard, Barrett, Crucian, Doty & Heilman, 2002). There is something special about the dimension left-right in the human brain, people find it more difficult to discriminate between left and right, than between up and down or front and back (Farrell, 1979; Ofte & Hugdahl, 2002). Gerstmann himself reported that patients with his syndrome only experienced corporeal left-right problems, that is problems with comprehending space in relation to their own body. He also noted that right–left disorientation often occurred `with special reference to the hands and fingers' (Gerstmann, 1957). However, since Gerstmann's observations, many Gerstmann cases have been reported that demonstrate extracorporeal left-right difficulties (Alexander & Money, 1966) therefore, experiments will be presented that test both corporeal and extracorporeal spatial abilities. It is predicted that synaesthetes will show poorer performance than controls on both tasks. The corporeal task will require participants to determine whether presentations of hands, in varying orientations, are images of a left hand or a right hand, so it is predicted that synaesthetes will perform more poorly for this task than the extracorporeal task.

In order to identify potential difficulties in processing number at a more basic level than arithmetic a subitizing experiment will be conducted. Random dot patterns have been employed in several experiments to assess ability to discriminate numerosity (Taves, 1941; Fink, Marshall, Gurd, Weiss, Zafiris, Shah, Zilles, 2000). The number of dots in an array and the arrangement of the dots has a profound effect on the response times when counting the number of dots in the array. Up to around four dots, participants are very quick to count the number of dots presented, this rapid counting has been referred to as subitizing. Within the subitizing range there is an increase of between 40 – 120 ms for each additional dot, whereas for greater numbers of dots there is an increase of between 250 – 350 ms for each additional dot (Trick and Pylyshyn, 1993). Some argue that the mechanism underlying the subitizing effect is distinct from counting (Atkinson, Francis & Campbell, 1976). The aim of the following experiment is to determine whether synaesthetes are able to subitize or whether a different pattern of counting is observed. As discussed in the introduction, Turconi and Seron (2002) presented a double dissociation of ordinal and cardinal number processing. Ordinal number processing involves reference to sequence representation which is required in subitizing. If synaesthetes have a problem with ordinal number processing, it follows that they should show impaired responses on the subitizing experiement. This may present itself as a lack of a typical subitizing effect or slower reaction times as compared with the control group.

3.2 PARTICIPANTS – CHAPTER OVERVIEW

From the 387 participants who completed the questionnaire, a pool of 19 synaesthetes and 19 control participants volunteered to take part in further objective testing. All synaesthetes who participated in the experimental tasks were grapheme colour synaesthetes, experiencing colours for visual or auditory presentations of letters, numbers and words.

In order to effectively match the synaesthesia and control groups, all participants were tested on the National Adult Reading Test (NART, Nelson, 1978). The NART required participants to correctly pronounce a list of typed words that increased in difficulty of pronunciation. The NART scores represent the predicted full IQ, calculated from the number of errors made, with a mean scaled score of 100. The results showed that the predicted NART-IQ for synaesthetes is well above average (100) and there was no significant difference between the synaesthesia and control groups for the NART (synaesthetes: mean 118.8 s.d. 4.2, controls: mean 117.2, s.d. 3.7).

As well as being matched on NART-IQ, as reported above, both groups were matched for sex (synaesthetes: 15 females and 4 males and controls: 15 females and 4 males) and age (synaesthetes: mean 35.9 years, range 18-64 years, controls: mean 32.2 years, range 18 – 65 years)

As described in the self-report questionnaire in Chapt. 2, all synaesthetes were tested for consistency to ensure their synaesthesia was genuine, the average consistency for the synaesthetes that participated in the experiments is 88.7%. Measures of consistency for individual participants are shown in the table below (Table 3.1). No measure of consistency was taken for these particular control participants, but they did not report synaesthesia.

Table 3.1 details the demographic data, NART scores and consistency measures for each of the synaesthetes that completed an experimental task described in this chapter. Whilst all synaesthetes completed the arithmetic task, and both spatial tasks, only a subset completed the subitize task. Similarly, the same participants from the control group completed all tasks apart from the subitize task, which was only completed by a subset of the controls.

Participant	Sex	Age	Consist. (%)	NART score	Arith Expt	Cross Expt	Hand Expt	Subitize Expt
AG	Female	38	97	120	✓	✓	✓	✓
JW	Female	48	90	128	✓	✓	✓	✓
CD	Female	18	74	118	✓	✓	✓	✓
KH	Female	29	100	113	✓	✓	✓	✓
KAH	Female	38	90	119	✓	✓	✓	✓
JE	Female	21	84	121	✓	✓	✓	✓
MH	Female	25	90	114	✓	✓	✓	✓
AL	Female	28	88	117	✓	✓	✓	✓
MW	Female	27	91	119	✓	✓	✓	✓
BL	Female	55	91	121	✓	✓	✓	✓
AD	Female	39	94	114	✓	✓	✓	
CG	Female	37	80	114	✓	✓	✓	
KW	Female	25	100	n/a	✓	✓	✓	
SG	Female	38	98	124	✓	✓	✓	
NS	Female	26	95	114	✓	✓	✓	
IB	Male	64	86	125	✓	✓	✓	✓
KA	Male	48	89	120	✓	✓	✓	
JAW	Male	45	94	119	✓	✓	✓	
RJ	Male	33	55	118	✓	✓	✓	

Table 3.1 Demographic data, NART scores and consistency measures for synaesthetes in experimental tasks

3.3 APPARATUS

The stimuli for the following 4 experiments were presented on a PC screen in black on a white background. Participants sat approximately 50 cm from the screen and at an appropriate height to ensure that the stimuli were clearly visible. A hand-held low impedance microphone was held by the participant near to the mouth in order to make spoken responses to the stimuli presented on the screen.

3.4 REACTION TIME EXPERIMENT FOR SIMPLE ARITHMETIC

3.4.1 Rationale and hypotheses

In line with the questionnaire data reviewed in chapter two, it is predicted that synaesthetes will perform poorly in comparison to the control group for each of the calculation categories (addition, subtraction and multiplication). In addition to self reports of poor arithmetic performance the literature review suggests that synaesthetes should show poorest performance for subtraction tasks. In line with our hypotheses that synaesthetes will demonstrate a Gerstmann's pattern of deficits, implicating impairments of the parietal cortex, we would expect synaesthetes to show the same impairments as the patient with the inferior parietal lesion described in Dehaene et al's (1997) study; that is, poor performance when solving simple addition and subtraction sums, yet normal, or less effected ability to retrieve rote multiplication facts.

Further analysis of the data will assess whether there are any differences between groups, dependant on the questionnaire data collated in chapter 2, regarding reported number/calculation problems and the presence of visual number forms. It is predicted that those reporting calculation problems and those reporting number forms will be significantly poorer at the arithmetic tasks than those who do not report difficulties or a number form.

3.4.2 Participants

19 synaesthetes (4 male, 15 female) and 19 control (4 male, 15 female) participants volunteered for the experiment.

3.4.3 Design

The stimuli consisted of simple arithmetical calculations that appeared in black against a white background. Stimuli were Times New Roman font, size 50 pt. Each problem comprised a simple calculation between two one-digit numbers (e.g. 5+3, 9-2, 7x4). The stimuli were divided into three distinct blocks (addition, subtraction and multiplication), with each block containing four practice items and 24 experimental items. Each item appeared on a computer monitor until a response was made, at which point the next item appeared. A fixation cross appeared in the middle of the screen between every stimulus with an interval (1500 ms following the participant's response) of 1000 ms between stimuli.

The experiment was analysed using a 2x3 design with the between subjects variable as subject type (control or synaesthete) and the within subjects variable as category of calculation (addition, subtraction, multiplication). It is hypothesised that there will be a significant difference between the synaesthesia and control group for each of the calculation categories, with the control group outperforming the synaesthesia group. Slower reaction times are expected for both groups for the multiplication task compared to the addition and subtraction tasks, as multiplication calculations are generally deemed to be harder. A Calculation Category x Subject Type interaction is also predicted, which would indicate that the difference in mean reaction time between the control and synaesthesia groups increases with the difficulty of task.

3.4.4 Procedure

Participants were required to respond as quickly as possible to the stimuli and to avoid making errors. Participants provided a spoken response into a microphone, which automatically recorded their response latencies in milliseconds from stimulus onset to response onset. Calculation errors, microphone errors and outliers (3 s.d. above the mean) were removed from the reaction time data.

3.4.5 Results

The data was analysed using a 2x3 repeated measures ANOVA. There was a significant main effect of calculation category, $F(1.45,52.06) = 41.72$, $p<.01$ (the Huyn-Feldt adjusted F statistic was used for data sets for which sphericity was rejected). As can be seen from Fig. 3.1 the multiplication task produced slower reaction times for both groups compared to the addition and subtraction categories. A Bonferroni correction revealed that there was a significant difference between the multiplication task and both the addition ($p<.01$) and subtraction ($p<.01$) groups, but no difference between the addition and subtraction groups. This is a standard finding as multiplication is accepted to be a more difficult task than addition or subtraction and the answers to the multiplication questions were of a greater magnitude, further accounting for the difference in reaction times across categories. Overall accuracy on the arithmetic tasks was high; the mean number of errors was low for both groups (synaesthetes = 1.5, controls = 2).

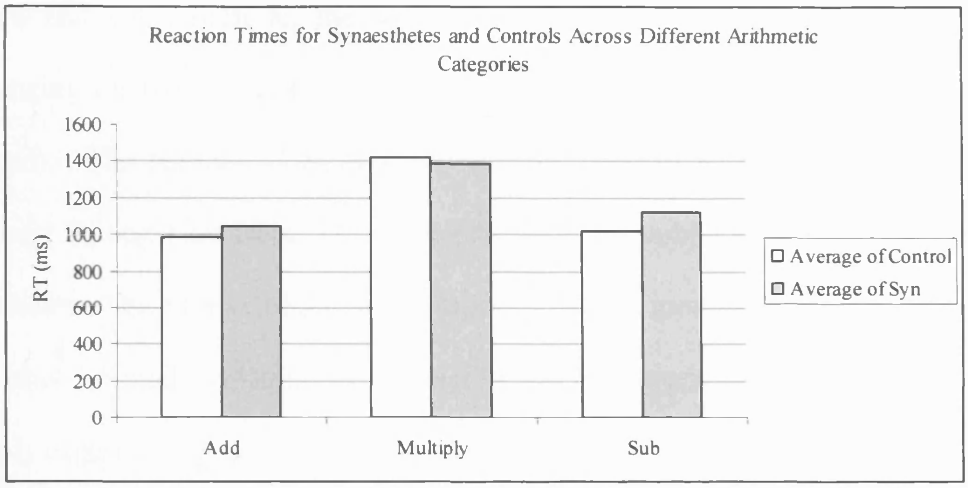

Fig. 3.1 Mean reaction times for synaesthetes and controls in each arithmetic category

There was no significant main effect of Subject Type, $F(1, 36) = .18$, $p>.05$, indicating that synaesthetes and control participants performed equally on the calculation tasks. Three separate independent samples t-tests were conducted, for each of the calculation conditions, but no significant differences were revealed. This does not fit with the hypothesis and although the trend is in the correct direction (synaesthetes reaction times were fractionally slower than controls) the difference is not sufficient to support the hypothesis. There was also no Calculation Category x Subject Type interaction, $F(1.45,52.06) = .564$, $p>.05$.

3.4.6 Reported problems and number forms

The results from the relevant section of the self-report questionnaire study were combined with the arithmetic data to see whether there was any correspondence between the subjective reports and objective findings. The following table (Table 3.2) details those participants that reported experiencing problems (the results for those who 'strongly agreed' and 'agreed' to reporting problems have been collapsed) with numbers and calculation on the self report questionnaire and those that reported experiencing number forms (similarly results for 'strongly agreed' and 'agreed' were collapsed). The number of participants reporting problems with number/calculation was lower amongst controls, 32% of controls report problems compared to 63% of synaesthetes. The number of problems reported for both groups are slightly higher than those who reported problems in the self-report questionnaire[1]. More synaesthetes reported experiencing number forms, 63% of synaesthetes compared to 31% of controls. Again the number of participants reporting number forms is slightly higher than the number reported in the self-report questionnaire[2]. Although the rates of number problems and visual number forms is higher for both groups than the figures presented for the questionnaire study in chapter 2, the fundamental relationship between the two groups is still the same; that is, there are more synaesthetes than controls that report both number forms and problems with number and calculation.

[1] Number problems reported in the self report questionnaire (n=387) - synaesthetes 47%, controls 20%
[2] Number forms reported in the self report questionnaire (n=387) - synaesthetes 53%, controls 9%

Control Group			Synaesthesia Group		
Participant	Number / Calculation Problems	Number Form Reported	Participant	Number / Calculation Problems	Number Form Reported
CM		✓	AG	✓	
AN		✓	JW		✓
KD			CAD	✓	✓
VX	✓		KH	✓	
FG	✓		KAH		✓
KG			JE		
GM		✓	MH		✓
SC	✓		AL	✓	✓
JK		✓	MW	✓	✓
MM			IB		✓
TM			BL		✓
NRG	✓		KA	✓	
KA			JAW	✓	
JBW			AD	✓	✓
MA		✓	CG	✓	
RB		Unanswered	KW		
EC			SG	✓	✓
ND	✓	Unanswered	RJ	✓	✓
ME	✓	Unanswered	NS	✓	✓

Table 3.2 Arithmetic: Participants that reported problems with numbers / calculation and number forms

Taking this questionnaire data into account, further analyses were conducted to elucidate any differences between groups, dependant on whether difficulties were reported with calculation and whether visual number forms were reported.

The control and synaesthesia groups were treated as one data set and divided into two groups; those reporting, and those not reporting calculation problems. There was a significant difference between the two groups in the logical direction; those who reported experiencing problems with number and calculation performed more poorly than those not reporting problems on all the calculation tasks, $F(1,36) = 9.97$, $p<.005$. This is an indicator that the tests are sensitive to the differences in calculation ability.

When each of the groups (synaesthesia and control) were divided into sub-groups, dependant on whether they reported problems with numbers, a trend emerged (see Fig. 3.2, below). Both the synaesthesia and control groups that reported problems with number showed slower reaction times than the groups that did not report number problems. The slowest reaction times were observed amongst the synaesthesia group that reported problems. A 2x2x3 ANOVA revealed no differences of statistical significance but the trend indicates that synaesthetes that report problems are worse than both control groups (with and without reports of problems), $F(1.55,52.57) = .40$, $p>.05$.

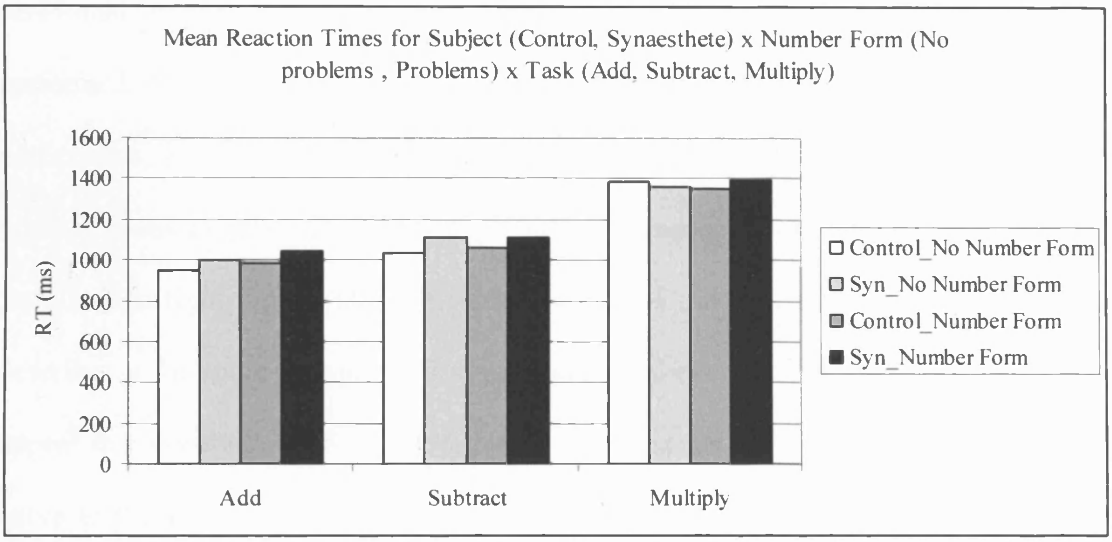

Fig. 3.2 Mean reaction times for synaesthetes and controls grouped by reports of number problems

Finally, when each of the groups (synaesthesia and control) were divided into sub-groups, dependant on whether they reported experiencing a visual number form, no clear trend appeared, $F(1.49,46.04) = .12$, $p>.05$. The presence of a number form did not lead to poorer performance as predicted. It may be that the presence of a number form simply has no bearing on participant's performance on arithmetic tests; based on subjective data however, this seems unlikely. When synaesthetes are asked to describe their number forms they are often very elaborate and in some cases can take very convoluted forms; some subjects remark that it is difficult for them to do arithmetic because of their number form that they 'have to use'. On the other hand, many synaesthetes reported very clear number forms running from left to right, forming a more logical order for numbers that may in fact facilitate number processing. This hypothesis will be tested in more detail in the following chapter but before then it is worth considering some of the participants who completed this task, whose performance may have been facilitated or inhibited by their number form. The two participants that performed fastest on the arithmetic tasks overall and the four participants that performed the slowest overall all reported number forms. The two quickest participants, IB and BL were synaesthetes that described the numbers 1 to 10 of their number forms as appearing in a straight line; IB's running vertically and BL's running from left to right with a slight ascension. Out of the four slowest participants, one describes a far more complicated visual number form. For AD the numbers 1 to 6 appear in a generally vertical line (starting with 1 at the bottom) with a slight concave curve to the right, after which there is a gap before the numbers 7 to 10 appear in a vertical line running in the opposite direction, this clearly presents a more difficult number form on which to base number processing and may explain the slower performance on the experimental tasks.

3.5 CROSSROAD TASK - TIMED LEFT/RIGHT SPATIAL JUDGEMENT

3.5.1 Rationale and hypotheses

The reports of left/right discrimination amongst synaesthetes (Cytowic, 1989); as supported by the questionnaire data in chapter 2 demands further investigation into spatial processing amongst synaesthetes, utilising objective methodology. Poor performance amongst synaesthetes on tasks requiring left/right discrimination would fit with the theory that synaesthetes experience Gerstmann-like cognitive difficulties. It is therefore predicted that there will be differences between the synaesthesia and control groups on both the objective spatial tasks detailed below. It is predicted that synaesthetes will be slower to respond to a crossroad direction task, whereby the direction of travel of an imaginary car has to be determined giving a "left" or "right" response. It is also predicted that synaesthetes will be slower to state whether a photographic image of a hand is a "left" hand or a "right" hand. It is further predicted that for both tasks the degree of mental rotation will impact on the response time, in line with the mental rotation research (Shepard and Metzler, 1971). If the problem is with left-right judgements and not mental rotation then it is also predicted that there will be no Group x Rotation interaction. Amongst the corpus of tests Mayer et al (1999) presented their Gerstmann case, HP, there was a test of mental rotation. Although HP's performance was worse than that of controls for the baseline task, his performance decreased in the same proportion to that of control subjects as the amount of mental rotation, required to complete the task, increased. Whilst it is not predicted that synaesthetes will show impaired mental rotation, it will be used as a variable to avoid misattributing potential differences in the results.

3.5.2 Participants

19 synaesthetes (4 male, 15 female) and 19 control (4 male, 15 female) participants volunteered for the experiment.

3.5.3 Design

The design comprised basic patterns depicting a 'crossroad' and two arrows: an arrow with a broken line that indicated the direction in which the participant was to imagine travelling in and an arrow with a straight line indicating the direction they were to imagine taking upon reaching the junction. The crossroad measured 130 mm x 130 mm and the arrows were 32 mm long, all of the lines were 1 mm thick. There were 48 trials in total; in half of which the 'crossroad' appeared in an upright position (e.g. Fig. 3.3a) and the other half in which the crossroad had been rotated by 45° (e.g. Fig. 3.3b). There were four possible starting positions: up, down, left and right for each configuration. There were 8 possible combinations of arrow positions and each combination appeared three times for each configuration (8x3x2=48 items). Each item appeared on the computer monitor until a response was made, at which point the next item appeared. A fixation cross appeared in the middle of the screen between every stimulus with an interval (1500 ms following the participant's response) of 1000 ms between stimuli.

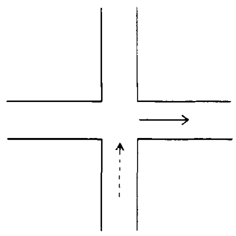	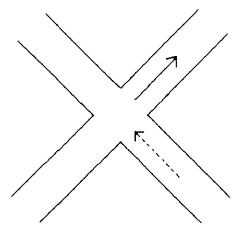
a. Upright Crossroad	b. Rotated Crossroad

Fig. 3.3 Example crossroad stimuli

A 2x5 design was applied, with a between subjects variable of subject type (control or synaesthete) and within subjects variable of degree of mental rotation required to bring the dotted line arrow in line with the subjects point of view. The dotted line arrow indicates the starting point of the stimulus and there were 16 different starting points, according to the compass points therefore the degree of rotation, whether to the left or right was broken down into 0°, 45°, 90°, 135° and 180°. According to previous research the degree of mental rotation required to complete a task will lead to a directly proportional increase in reaction time (Shepard & Metzler, 1971). As this task is likely to require the subject to mentally rotate the crossroad to their point of view in order to complete the task it is predicted that the reaction time will increase as the degree of mental rotation increases. It is predicted that any difference in results between controls and synaesthetes will be attributed to the ability to discern left and right rather than an ability to mentally rotate.

3.5.4 Procedure

Participants were required to perform a right/left orientation decision. Participants were presented with a stimulus and instructed to imagine they were looking at a crossroad. Participants provided a 'left' or 'right' spoken response accordingly, into a microphone.

Incorrect answers and premature triggers of the microphone were noted and removed from the reaction time calculations.

3.5.5 Results

Mean reaction times were calculated and entered into a 2x5 repeated measures ANOVA for each participant. The mean reaction time for synaesthetic and control participants are presented in Fig. 3.4. Results have been divided into degrees of mental rotation. As the graph shows there was an increase in reaction time for both control and synaesthetic groups as the degree of mental rotation increased with the slowest mean reaction time of around 1240 ms for the 180° rotation stimuli.

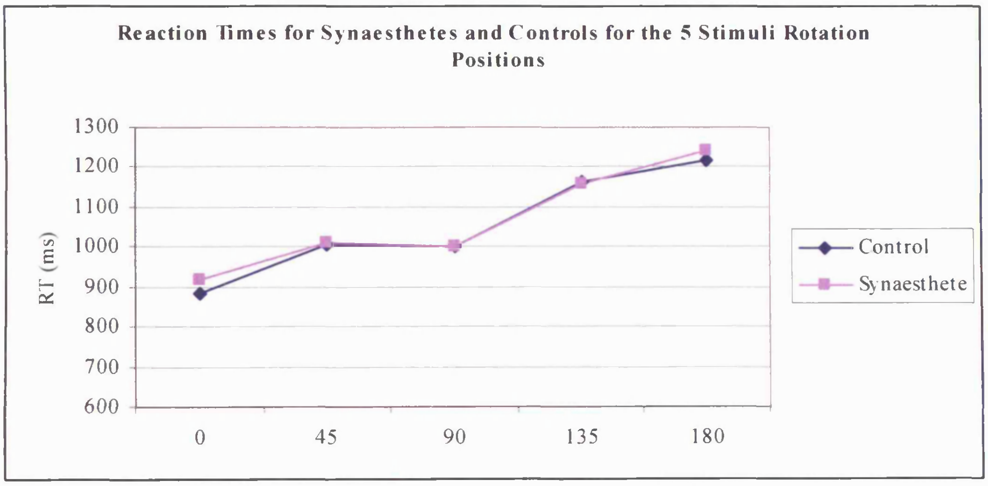

Fig. 3.4 Mean reaction times for the 5 rotation positions of the crossroad task

As predicted, there was a significant main effect for the degree of rotation $F(2.27, 81.77) = 38.91$, $p<.005$. However, there was no Rotation x Subject effect $F(2.27, 81.77) = .12$, $p>.05$, indicating that the degree of mental rotation required to complete the task did not disproportionately effect the synaesthesia group. There was also no significant difference in accuracy of responses between synaesthetes and controls, both groups averaging only one error for the task (range 0 – 5 for synaesthetes and 0 – 3 for controls).

3.5.6 Reported Problems

The results from the relevant section of the self-report questionnaire study were combined with the crossroad data to see whether there was any correspondence between the subjective reports and objective findings. Table 3.3 details those participants that reported experiencing problems (the results for those who 'strongly agreed' and 'agreed' to reporting problems have been collapsed) with left/right confusion. The number of participants reporting problems was not reliably different amongst controls (42%) than synaesthetes (44%). The number of problems reported for the control group is higher than those who reported problems in the self-report questionnaire, whilst the number of synaesthetes reporting problems is the same as the larger population[3].

[3] Left/Right Confusion problems reported in the self report questionnaire (n=387) - synaesthetes 44%, controls 24%

Control Group		Synaesthesia Group	
Participant	Left / Right Confusion Reported	Participant	Left / Right Confusion Reported
CM		AG	
AN	✓	JW	
KD		CAD	
VX	✓	KH	✓
FG	✓	KAH	✓
KG		JE	
GM	✓	MH	
SC	✓	AL	unanswered
JK		MW	
MM		IB	unanswered
TM		BL	unanswered
NRG	✓	KA	✓
KA		JAW	✓
JBW		AD	✓
MA	✓	CG	✓
RB		KW	
EC		SG	
ND	✓	RJ	✓
ME		NS	

Table 3.3 Left/Right: Participants that reported problems with left/right confusion

Taking this questionnaire data into account, further analyses were conducted to elucidate any differences between groups, dependant on problems reported. When divided into subgroups, a slight trend appears; both the synaesthesia and control groups that reported left/right confusion, showed slower reaction times than the groups that did not report number problems (see Fig. 3.5, below).

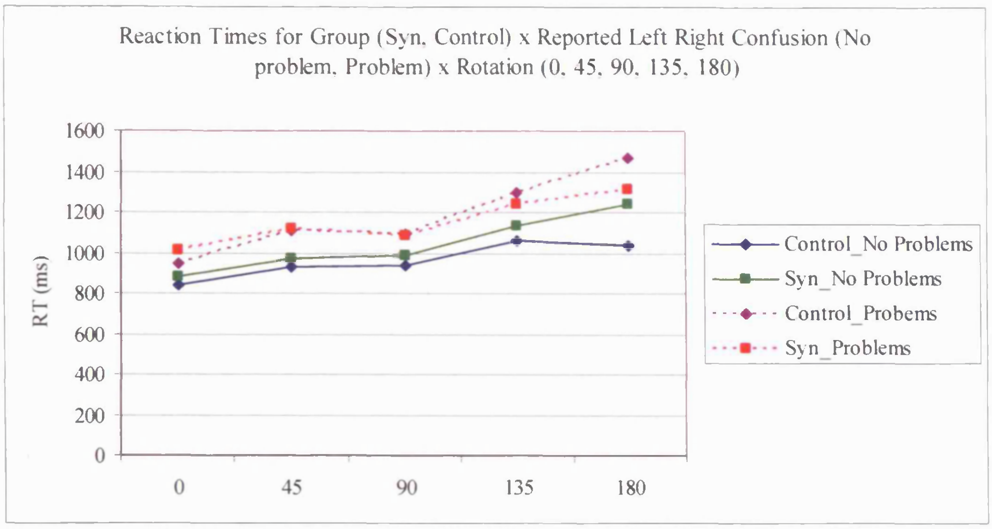

Fig. 3.5 Mean reaction times for synaesthetes and controls grouped by reports of number problems

A 3-way interaction (2x2x5) was conducted, comparing group (synaesthesia vs control), problems reported (problems vs no problems) and degree of rotation (0°, 45°, 90°, 135°, 180°). For the within subjects effects there was a main effect of rotation, as reported above, but no Rotation x Group. There was no Rotation x Problem interaction, $F(2.62, 81.29) = 1.41$, $p>.05$.

For the between subjects effect there was no main effect of Group, $F(1,31) = .13$, $p>.05$, but there was an effect of problem (left/right confusion), $F(1,31) = 4.81$, $p<.05$ Finally, there was a Group x Problem x rotation interaction, which indicates that there was a significant difference in reaction time between a problem synaesthesia group, problem control group, a normal synaesthesia group and a normal control group for the some rotation conditions, $F(2.62,81.29) = 2.82$, $p=.051$. As the significance was borderline, no further analysis was conducted on this interaction.

Against the predictions for this task, there were no differences between synaesthetes and control participants. Before concluding that synaesthetes do not display cognitive weaknesses aligned with Gerstmann syndrome, as suggested by the central hypothesis, it is worth investigating whether there are any tests that are more sensitive to differences that may exist between the groups. As the literature suggests that left right spatial difficulties amongst Gerstmann patients tend to be corporeal in nature we may expect to see greater differences between synaesthetes and controls for a task that more closely tests corporeal abilities; this will be addressed in the following task.

3.6 HAND TASK - TIMED LEFT/RIGHT SPATIAL JUDGEMENT

3.6.1 Rationale and Hypotheses

The second test of spatial ability examined participant's ability to make left/right judgements in egocentric space. Poor performance would indicate a difficulty in processing information in relation to the body. Because the stimuli are of hands, and Gerstmann specifically described his patients as having spatial difficulties 'with special reference to the hands and fingers' (Gerstmann, 1957), it is predicted that synaesthetes will show a greater difference from the control group than on the cross road task.

It was predicted that before a left/right hand judgement could be made, the participant would mentally organise the image of the hand to a more familiar position. It was therefore predicted that reaction times would be slower for conditions requiring mental rotation or conditions with stimuli in less familiar positions, such as a hand with closed fingers facing palm up. It was also predicted that stimuli with closed fingers will produce slower reaction times not only because the hand is seen less frequently in the closed position but also because a fist shape presents a more ambiguous shape from which to distinguish left from right. It was predicted that any difference in results between controls and synaesthetes will be attributed to the ability to discern left and right rather than an ability to mentally rotate.

3.6.2 Participants

19 synaesthetes (4 male, 15 female) and 19 control (4 male, 15 female) participants volunteered for the experiment.

3.6.3 Design

The stimuli comprised black and white photograph images of human hands, both left and right, from various viewpoints (Fig. 3.6). There were 60 trials in total. In half the trials the stimuli appeared in a standard configuration (e.g. Fig. 3.6b), as the participant would expect to see if looking down at one of their own hands (e.g. with the wrist closest to the body). The other half of trials appeared in an inverted configuration (e.g. Fig. 3.6h), as if the participant was looking at the hand of a person sat directly opposite them. Further variations in the hand images involved a combination of different finger arrangements, from fully closed, like a fist, through to fully splayed open. Each of the variants appeared in both palm facing up and palm facing down positions. The image size varied between 90 and 120 mm wide and 90 – 120 mm high, dependant on whether the fingers were furled, extended or splayed.

Each item appeared on the computer monitor until a response was made, at which point the next item appeared. A fixation cross appeared in the middle of the screen between every stimulus with an interval (1500 ms following the participant's response) of 1000 ms between stimuli.

A 4-way ANOVA (2x2x2x2) design was applied to this experiment. The between subjects variable was subject type (control or synaesthete) and the 3 within subjects variables were different hand orientations, each with 2 levels. In order to control for effects of mental rotation and unfamiliar postures the hand orientation was treated as an experimental variable. The orientation of the hand was coded for three different factors and for each factor there were two possible positions. The factors were; 'overall orientation' whereby the hand was in either a normal (as if the participant was looking down at their own hand) or inverted (as if the participant was looking at the hand of a person in front of them); 'palm position' whereby the palm was facing up or down and; 'finger position' whereby the fingers were either open or closed. Each of the orientation conditions had between 6 and 9 different stimulus presentations making 60 stimuli in total (see Fig. 3.6 for examples of stimuli in each of the 8 possible configurations).

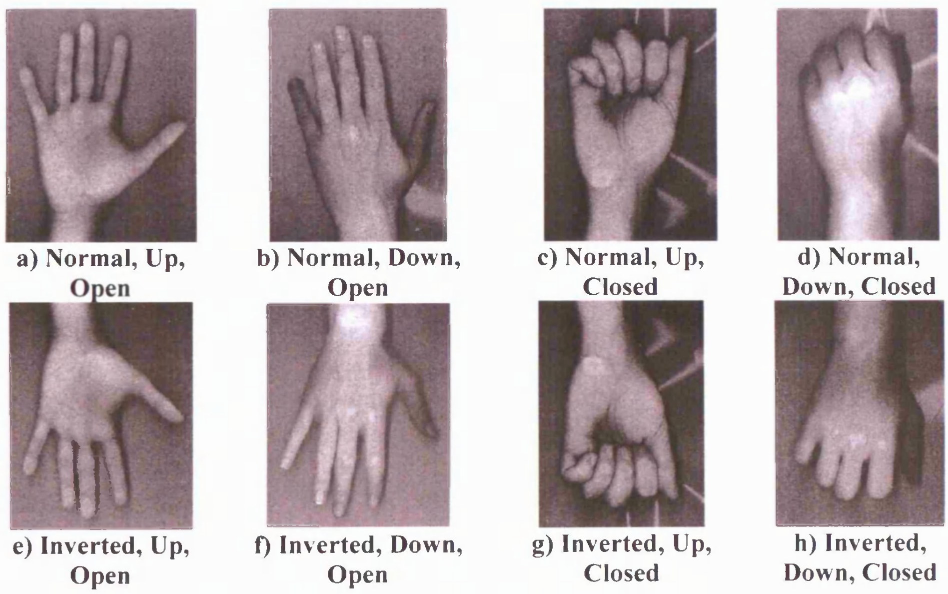

Fig. 3.6 Example hand stimuli in each of the 8 configurations

3.6.4 Procedure

Participants were required to perform a right/left judgement decision. Participants were presented with a stimulus and were instructed to say whether the hand was a left hand or a right hand. Participants provided a 'left' or 'right' spoken response accordingly, into a microphone. Incorrect answers and premature triggers of the microphone were noted and removed from the reaction time calculations.

3.6.5 Analysis and Results

Controls demonstrated slightly higher mean error rates than synaesthetes (control = 13, synaesthete = 11), and the rates were higher for both groups than error rates for the crossroad task (reported above). The mean reaction times for each of the eight hand configurations are shown in Fig. 3.7 below. The graph shows that, contrary to predictions, controls were slightly slower than synaesthetes in all conditions. This difference did not reach significance however, $F(1,35) = .575$, $p>.5$ [4], nor was there a group x condition interaction, which indicates there was no difference in performance on the spatial tasks between the two groups.

[4] Note that the d.f. is not 36 as no data was available for one of the hand orientations for one of the control participants (owing to a combination of errors and microphone errors).

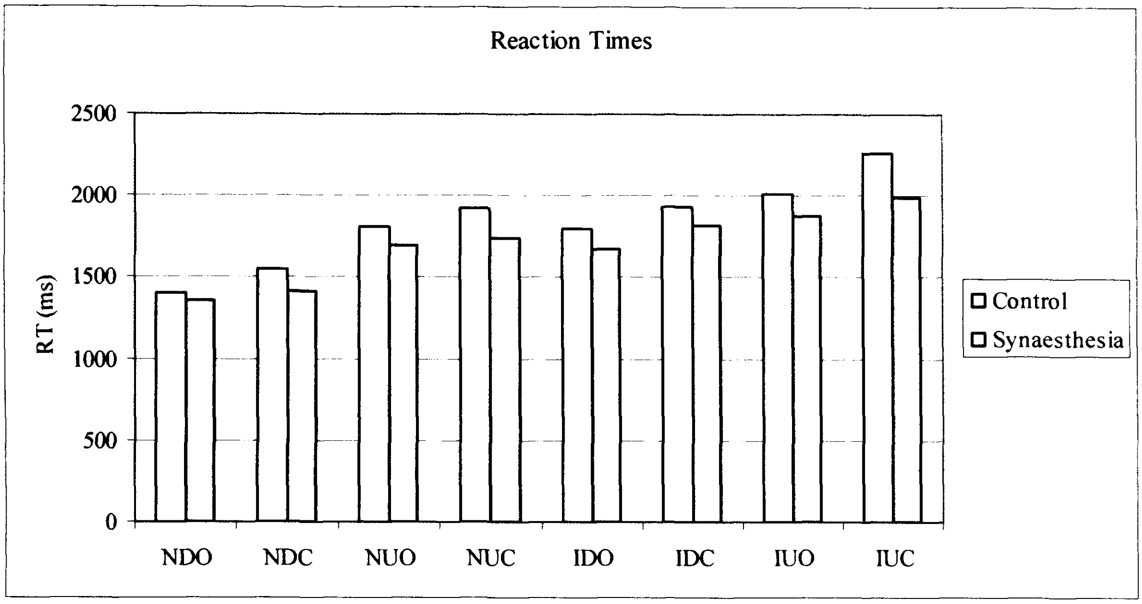

Fig. 3.7 Mean reaction times for each of the eight hand configurations

NDO	=	Normal Down Open
NDC	=	Normal Down Closed
NUO	=	Normal Up Open
NUC	=	Normal Up Closed
IDO	=	Inverted Down Open
IDC	=	Inverted Down Closed
IUO	=	Inverted Up Open
IUC	=	Inverted Up Closed

The 2x2x2x2 ANOVA revealed within subjects main effects for all three categories; 'overall orientation', $F(1, 35) = 15.5$, $p<.005$; 'palm position', $F(1,35) = 16.53$, $p<.005$; and 'fist', $F(1, 35) = 5.66$, $p<.05$. These differences are less relevant to the hypothesis but indicate that the tests were sensitive and that the degree of mental rotation required before a left-right decision could be made impacted on the reaction time. All the images presented in the normal position (that is all the bars in Fig. 3.7 that have a three letter code beginning with 'N' for normal) produced faster reaction times than images presented in the inverted position (all bars beginning with 'I' for inverted). This suggests that participants did mentally rotate the images to body-centred coordinates. There were no group x hand position interactions for 'overall orientation', 'palm' or 'fist' positions.

3.6.6 Reported Problems

As with the cross road study, the results from the relevant section of the self-report questionnaire study were combined with the hand data to see whether there was any correspondence between the subjective reports and objective findings. The number of participants reporting problems ('strongly agree' or 'agree') when asked "Do you find that you often get left and right confused?" was slightly lower amongst controls (42%) than synaesthetes (44%), for a breakdown by participant, see Table 3.3, above.

On the basis of these subjective reports, the groups were divided into subgroups. Unlike the crossroad task, reported problems in the self-report questionnaire were not a good predictor of performance on the objective hand task. There was little difference in overall mean reaction times between the two control subgroups; controls reporting problems averaged 1789ms and controls reporting no problems averaged 1760ms (Fig. 3.8). The synaesthetes show counterintuitive results; synaesthetes reporting problems averaged 1627 ms whereas synaesthetes reporting no problems averaged 1843ms. When the mean reaction times for the 4 sub-groups are plotted for the 8 different hand orientation positions, an interesting pattern occurs. Not only are the synaesthesia group that report problems the quickest for the majority of rotations but they also show little variation across the different hand orientation groups; this may suggest that they are employing a strategy for completing the task that masks the expected effect that is observed in all the other groups. It could be that the synaesthetes are just guessing, avoiding a rotation of the inverted hand stimuli, however error rates for synaesthetes with problems were low (Fig. 3.9). The highest average error rates were observed for the control groups reporting problems; the highest individual error score for a hand position was 6 errors.

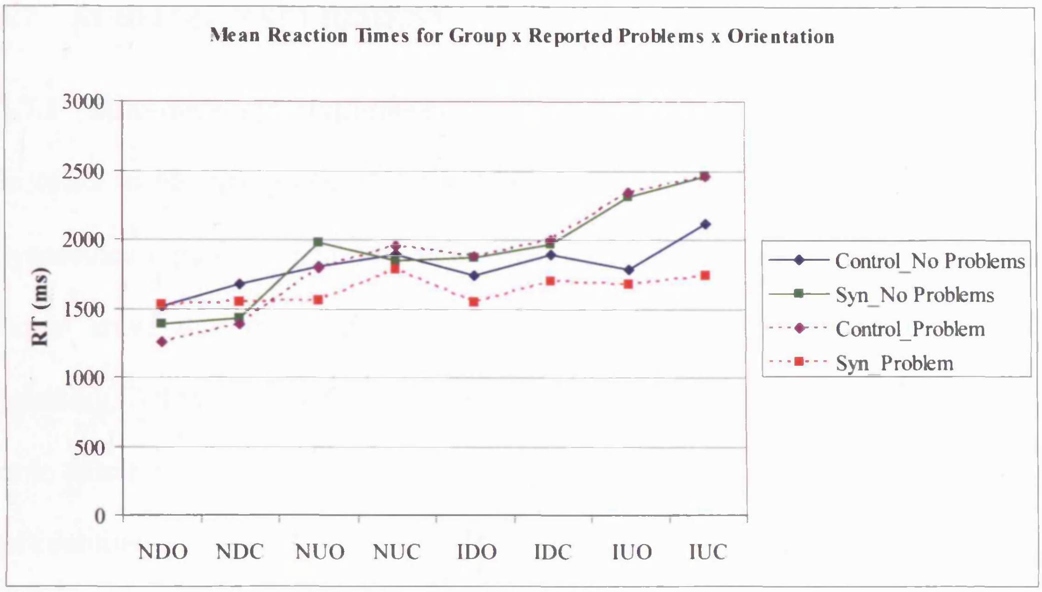

Fig. 3.8 Mean reaction times for synaesthetes and controls grouped by reports of left / right problems

(NDO = Normal Down Open, NDC = Normal Down Closed, NUO = Normal Up Open, NUC = Normal Up Closed, IDO = Inverted Down Open, IDC = Inverted Down Closed, IUO = Inverted Up Open, IUC = Inverted Up Closed)

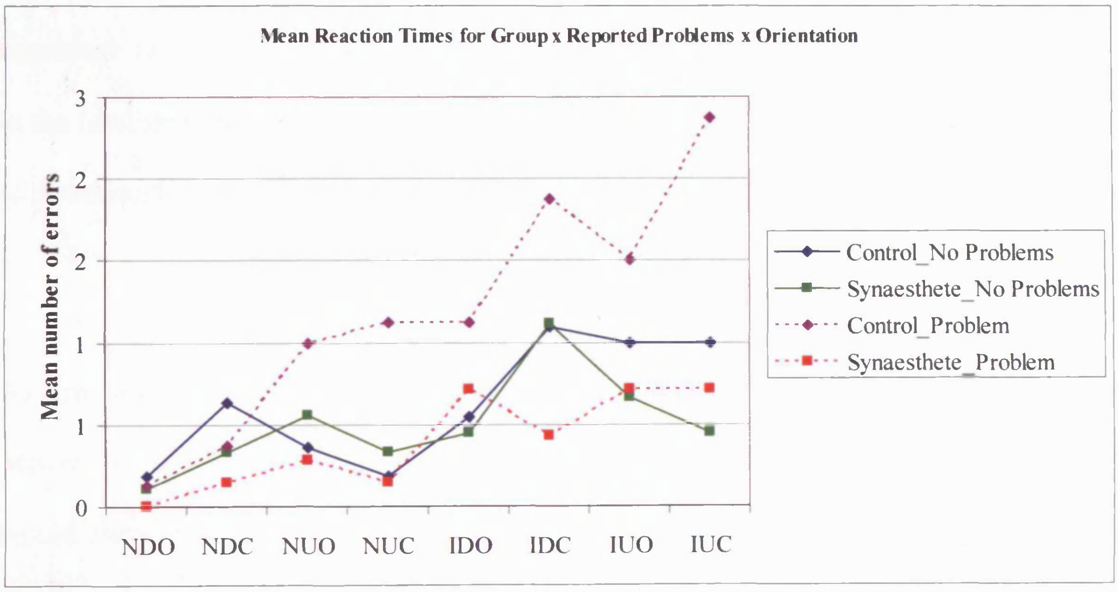

Fig. 3.9 Mean error rates for synaesthetes and controls grouped by reports of left / right problems

(NDO = Normal Down Open, NDC = Normal Down Closed, NUO = Normal Up Open, NUC = Normal Up Closed, IDO = Inverted Down Open, IDC = Inverted Down Closed, IUO = Inverted Up Open, IUC = Inverted Up Closed)

3.7 SUBITIZE EXPERIMENT

3.7.1 Rationale and Hypotheses

In order to identify potential difficulties in processing number at a more basic level, synaesthetes performance was compared with controls on a subitizing experiment. Some argue that the mechanism underlying the subitizing effect is distinct from counting (Atkinson, Francis & Campbell, 1976). The aim of the following experiment is to determine whether synaesthetes are able to subitize or whether a different pattern of counting is observed.

The experiment covered both random dot configurations and canonical dot configurations. The 'subitizing' stimuli, those from numbers 1 to 4 appeared in a random configuration, as did the 'random' stimuli, those from numbers 5 to 9. The canonical stimuli were defined by their familiarity; stimuli were either symmetrical or in the familiar configurations seen on dice. Canonical arrays ranged from 5 to 9 dots, as with the random stimuli.

As discussed in chapter 1 Turconi and Seron (2002) presented a double dissociation between cardinal and ordinal number processing and it was predicted that synaesthetes would show a deficiency in ordinal number processing. One of Turconi and Seron's observations was that patient CO, who was unable carry out ordinal number processing, had difficulty in counting arrays of dots. It was therefore predicted that synaesthetes would show a different pattern of response for counting dot arrays than controls. It was predicted that, for the random stimuli, control participants would subitize random dot configurations up to four dots, showing a greater increase in reaction time for each additional dot in the array after four. For synaesthetes it was predicted that the underlying ability to count would be irregular, demonstrating no subitizing ability. Instead a consistent increase in reaction time would occur with the addition of each new dot in the array. It was also predicted that the mean reaction time would be greater for each array.

For canonical stimuli on the other hand, due to their familiarity, it was predicted that both groups would demonstrate quicker responses and that no difference between the groups would be observed for either response pattern or mean reaction time as the number of dots increased. As both synaesthetes and controls are exposed to canonical shapes, they are both likely to experience a familiarity effect, rather than having to rely on counting.

It is further predicted that the response times for the highest number in the sequence, in this case the 9-dot array, will produce quicker responses than the 7 and 8 dot arrays. This is based on the literature which commonly reports a 'guessing end-effect' whereby participants work out the biggest dot array in the sequence and simply guess at it rather than trying to count it (Simon, Peterson, Patel, Sathian, 1998)

3.7.2 Participants

11 synaesthetes (1 male, 10 female) and 6 control participants (1 male, 5 female) volunteered for the experiment.

3.7.3 Design

Stimuli consisted of dot arrays varying in number of dots; between 1 and 9, and varying in configuration; either random, subitizeable or canonical. Stimuli were created using a 9 x 7 rectangular grid. Dots were 2.5 mm in diameter and a minimum distance of 2.5 mm apart. When presented on the screen, dots appeared in black on a white background in the centre of the screen.

The placement of dots within the grid varied for the three stimulus groups. For the 'subitizing' group the numerosities 1,2,3 & 4 were arranged in the grid at random; for the 'random' group numerosities 5,6,7,8 & 9 were placed at random in the grid and; for the 'canonical' group the numerosities 5,6,7,8 & 9 were arranged in the grid following established protocol (see Fig. 3.10 for examples and Appendix B for a diagram of all arrays).

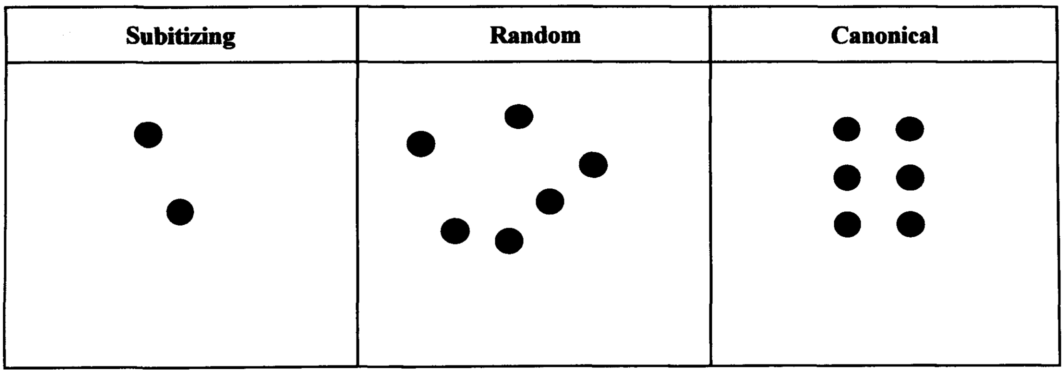

Fig. 3.10 Example subitize stimuli subitize (2), random (6) and canonical (6) category examples

Two blocks of 56 trials were completed, making 112 trials in total. Each stimulus appeared 8 times in a quasi-random order over the two blocks, with no two stimuli appearing more than twice consecutively. Each item appeared on the computer monitor until a response was made, at which point the next item appeared. A fixation cross appeared in the middle of the screen between every stimulus with an interval (1500 ms following the participant's response) of 1000 ms between stimuli.

3.7.4 Procedure

Participants were required to say how many dots were on the screen "as quickly and accurately as possible". The experimenter was careful not to use the word 'count' so as not to influence the strategy used by the participant to determine how many dots there were. A rest period was provided between blocks if required. Incorrect answers and premature triggers of the microphone were noted and removed from the reaction time calculations.

3.7.5 Results

The mean reaction times were calculated for each of the nine stimulus types in the standard subitizing experiment (subitize 1, subitize 2, subitize 3, subitize 4, random 5, random 6, random 7, random 8, random 9) for each of the two groups. The synaesthesia and control groups performed similarly on the two experiments, as supported by a t-test comparing the two sets of means that did not reach significance, $t = .65$, $p>.05$.

As predicted, there was a difference in the reaction times for the randomly arranged dots vs. the canonical dots, $F(1,14) = 132.57$, $p< .001$. The canonical dots were counted more easily than the randomly arranged dots due to their familiar arrangements. Fig. 3.11 shows the mean reaction times across the two groups and the same overall pattern is seen for both the random and canonical data. There is a peak in reaction time for the

7 dot stimuli, with a slightly lower reaction time for the 9 dot stimuli; the guessing end-effect.

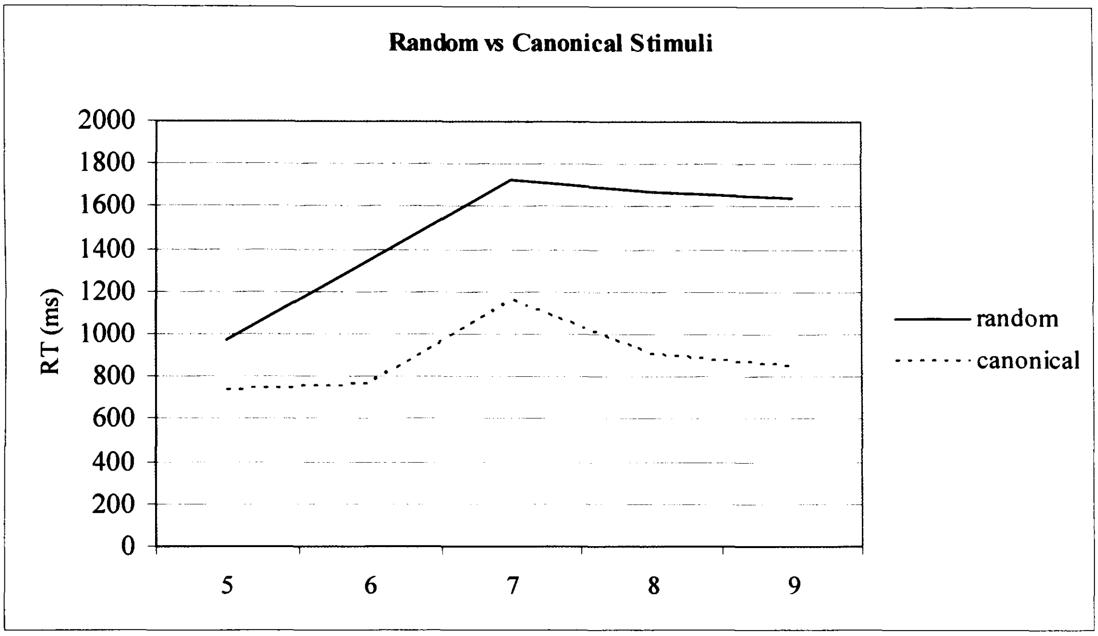

Fig. 3.11 Subitize: Mean reaction times for random vs canonical stimuli

The only difference between the two groups that stands out from Fig. 3.12 is the mean reaction time for the 8 dot stimuli. The control group were quicker to respond to the 8 dot presentations than the synaesthesia group (1877 ms vs 1552 ms), but the difference did not reach significance, $t = 1.78$, $p>.05$. This trend may indicate that synaesthetes are less effective at counting larger arrays of dots and further differences may be observed if the two groups were required to respond to larger arrays e.g. 10 – 20 dots.

In line with the hypothesis both groups produced a quicker response for the 9-dot array than the trend of the graph would predict. This is due to the "guessing end-effect" where participants become aware of the upper limit to the number of dots and purely guessed the number of dots for the nine and eight arrays, hence the quicker responses.

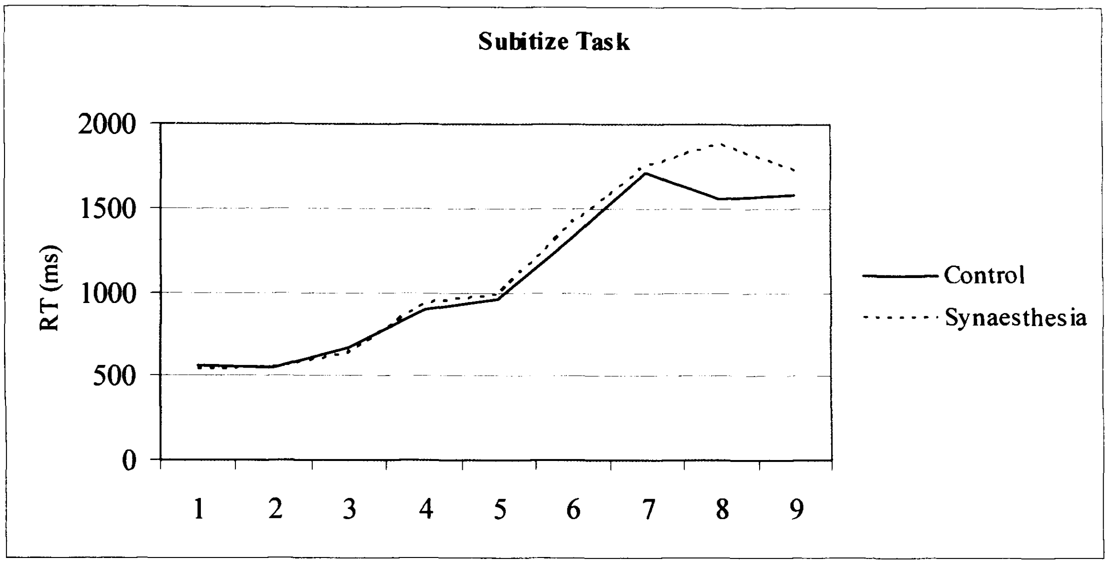

Fig. 3.12 Mean reaction for the nine stimulus types

There is evidence of the subitizing effect. The slope of the means plot for the first four stimuli (sub 1, sub 2, sub 3, sub 4) was 110 ms for controls and 125 ms for synaesthetes. The slope for the numbers for the higher numbers (ran5, ran7) however, was 377 ms for controls and 386 ms for synaesthetes. The steeper slope for the higher numbers indicates that there is a greater increase in reaction time, as the number of dots in the array increases, than the reaction time increase observed for the lower numbers. So, the general finding is partly in line with predictions, in that a subitizing effect is observed, but the effect only appears to be found for the arrays 1, 2 and 3. Arrays of 4 dots and greater, seem to rely on counting. The key factor for this study is that there was no significant difference between the groups, indicating that the ability for synaesthetes to subitize and count, basic measures of numerical ability, are intact.

3.7.6 Reported problems

The results from the self-report questionnaire study were combined with the subitize data to see whether there was any correspondence between the subjective reports and objective findings. The following table (Table 3.4) details those participants that reported experiencing problems with numbers and calculation on the self report questionnaire (the results for those who 'strongly agreed' and 'agreed' to reporting problems have been collapsed). The number of participants reporting problems with number/calculation was lower amongst controls, 33% of controls report problems compared to 45% of synaesthetes, which is similar to reported problems in the self-report questionnaire (controls 20%, synaesthete 47%).

Control Group		**Synaesthesia Group**	
Participant	**Number / Calculation Problems**	**Participant**	**Number / Calculation Problems**
SC	✓	AG	✓
JK		JW	
MM		CAD	✓
TM		KH	✓
NRG	✓	KAH	
KA		JE	
		MH	
		AL	✓
		MW	✓
		IB	
		BL	

Table 3.4 Subitize: Participants that reported problems with numbers / calculation

Reaction times for the 4 groups have been plotted for the subitize dot arrays (sub1, sub2, sub3, sub4) and the random dot arrays (ran5, ran6, ran7, ran8, ran9, see Fig. 3.13). All groups showed similar results for dot arrays 1 – 7, with synaesthetes experiencing problems showing fractionally slower reaction times. One interesting observation is that the end guess effect is shown for the 9 dot array for both control groups but actually starts earlier, at the 8 dot array, for the synaesthesia problem group. This may suggest that the synaesthetes are more prone to guessing than counting for higher numbers. This is also reflected in the higher mean error rate for both synaesthesia groups (Fig. 3.14). It should be noted that these experiments have small group sizes and therefore have limited statistical power.

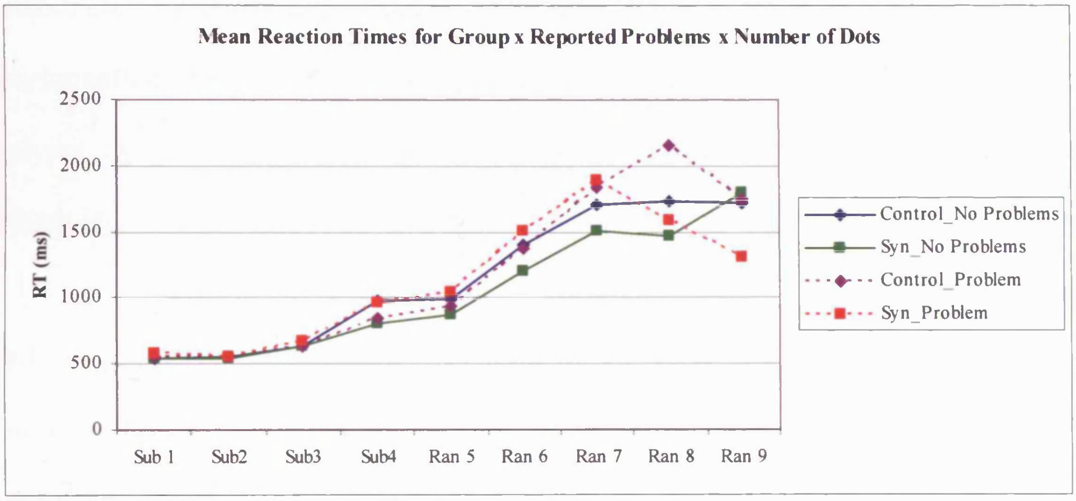

Fig. 3.13 Mean reaction times for synaesthetes and controls grouped by reports of number problems

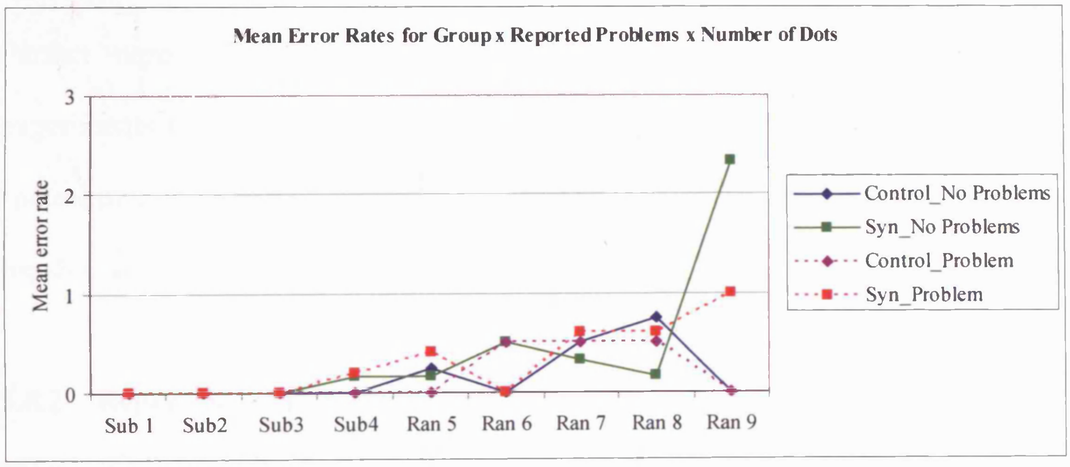

Fig. 3.14 Mean error rates for synaesthetes and controls grouped by reports of number problems

3.8 CHAPTER DISCUSSION

The fundamental message from the above analysis is that the difference between the performance of synaesthetes and controls is not stark and the performance does not clearly reflect the subjective questionnaire data reported in Chapter 2. Although synaesthetes report experiencing problems with calculation and left/right discrimination, and the problems reported in the literature too come from subjective analyses, there is no hard evidence for the existence of these problems when tested for objectively.

3.8.1 Are the tests sensitive?

It needs to be asked whether the tests are sensitive. Perhaps group differences exist but are not being tested for effectively? Evidence that suggests the tests were sensitive includes the difference in performance between those reporting problems and those not reporting problems and the difference in response times across calculation categories. Further support for the sensitivity of the tasks comes from similar reaction time experiments that yielded poorer performances for dyscalculic patients compared with control participants (e.g. Ashcraft, 1995 and Geary, 2004). That is, the same stimuli are capable of identifying group differences if they exist.

3.8.2 Representative sample?

There is a possibility that the sample of synaesthetes used for the study is not representative of the general synaesthetic population. Access to a wider sample of synaesthetes may reveal that there are more obvious cases of dyscalculia amongst the synaesthetic population, and a greater prevalence than one would expect amongst the normal population. It is clear that not all synaesthetes suffer from a strong mathematical disability or dyscalculia. Within the sample there is a mathematics teacher, an economist and many other professionals that require a strong grasp of mathematical concepts. Whilst 63% of the synaesthetes that participated in the objective study reported experiencing some difficulty with number / calculation, only 21% answered that they 'strongly agree' to experiencing difficulties.

A fundamental question that needs to be addressed is why so many synaesthetes report experiencing problems with numbers and calculation. It could be that synaesthetes struggled with mathematics when younger and have subsequently developed strategies to cope with their difficulties but still maintain a conception of being poor at maths. It should also be taken into consideration that the question was phrased as '...or have you ever experienced problems'; therefore it could be that problems were experienced when young, but have now largely been resolved. With the arithmetic tasks it may be that synaesthetes are simply well practised at completing such tasks in their everyday life and therefore any underlying difficulty is masked. This argument could also be levelled for the spatial tasks. The use of left/right discrimination for navigating ones environment in everyday life is vital and it is therefore understandable that people who are naturally poor at this may devise a heuristic to cope with the situation e.g. "right, the hand that I write with". If this heuristic is well practised then there may be no observable difference between heuristic responders and instinctive responders. This line of reasoning sets up the hypothesis that differences may be found in younger samples.

The increasing awareness of synaesthesia amongst the general population and especially amongst synaesthetes themselves may also influence people's perceptions of themselves. The majority of participants that completed the questionnaire in Chapter 2 volunteered after hearing a BBC Radio 4 broadcast on synaesthesia ("Hearing Colours, Eating Sounds"). This program reported the supposed difficulties experienced by synaesthetes and may have increased the likeliness of the synaesthetic participants reporting mathematical difficulties, in a 'bandwagon' manner. However, it is to be noted that we never mentioned in our recruitment that this was something that we were particularly interested in or that we were looking for synaesthetes with a particular profile.

Perhaps the most obvious explanation of the results is that, for the elements of number processing and spatial tasks tested here at least, there is no difference to be found between the control and synaesthesia groups.

Differences at a more basic level were also tested for in the form of the subitizing experiment. The data was analysed for overall reaction time and the pattern of counting as the number of dots increased however, the subitizing task produced no significant difference in results across the groups.

3.8.3 Subtle differences require further investigation

Although no support was found for the main hypotheses there are still some interesting differences between the groups that need to be looked at more closely. For the arithmetic task the performance of those synaesthetes experiencing incongruent mental number forms was poorer than the rest of the group. For example AD's mean reaction times for the addition and subtraction tasks were over 2.s.d greater than the mean. This implies that there may be a more subtle distinction to be drawn between the synaesthesia and controls groups. As the number of synaesthetes experiencing number forms is far greater than the number of control subjects experiencing number forms (63% vs 31% in this study) the reported differences may in fact be an indirect result of the number form. If this is the case then it should be possible to devise an objective test that makes a more direct assessment of the impact that synaesthete's mental number forms are having and thus a clearer distinction between the two groups may arise.

4 DISCUSSION

The central hypothesis of the present study was that synaesthetes would demonstrate impaired mathematical abilities and show signs of right-left confusability in line with the pattern of cognitive deficits observed in Gerstmann syndrome. The hypothesis grew from the subjective reports of cognitive weaknesses amongst synaesthetes from various small scale studies and found support in the questionnaire study conducted here, on a substantially larger scale. The objective data, however, reveals no significant difference between synaesthetes and controls for basic arithmetic and right-left distinction tasks. It is therefore concluded that these problems are not a ubiquitous feature of synaesthesia, although they may be present in a subset of synaesthetes.

One interesting finding from the self-report questionnaire was that those experiencing number forms tended to report difficulties with number and calculation. This raises the possibility that number forms in some way interfere with normal calculation; as more synaesthetes than controls experience number forms, perhaps reported problems with calculation are accounted for by the presence of number forms, or specific types of number forms.

As discussed in the literature review, it is suggested that the orientation of the mental number line is left to right with the most persuasive evidence coming from the SNARC effect (Spatial-Numerical Association of Response Codes); for parity judgements, participants are faster to respond more quickly to small numbers with their left hand and vice-versa (Dehaene et al. see Fig. 1.2). This was taken as evidence that reference was being made to a magnitude representation of number that is oriented from left to right; the left hand is able to respond to smaller numbers because they are closer to the left hand in mental space. Synaesthetes in the present study revealed the presence of many different number forms that did not fit the expected left to right pattern. Some described highly complex forms, which in some cases required mental rotation to utilise in arithmetic tasks. Perhaps the presence of a visual number form directly influences number processing. As the presence of number forms is significantly higher amongst synaesthetes it may explain why reports of number and calculation problems are higher amongst synaesthetes. Following this line of investigation, the central hypothesis would be redefined as: synaesthetes that experience irregular number forms will perform poorly on tasks involving spatial-numerical processing.

As discussed in the literature review, the most persuasive evidence for the orientation of the mental number line comes from the SNARC effect (Spatial-Numerical Association of Response Codes); whereby participants respond more quickly (e.g. on a parity judgement task) to higher numbers with their right hand and smaller numbers with their left. If we can assume that the mental number line that the SNARC effect reveals, is functionally equivalent to the magnitude representation that is central to the Triple Code model we are able to develop this argument, guiding further research. Do all people share a similar mental number form or are there differences? Could we expect to see different or reversed SNARC results for those who experience a right to left mental number line?

As mentioned earlier, there is evidence to suggest that the SNARC effect may be affected by reading direction; some Iranian born French citizens demonstrated a reversed SNARC effect, i.e. they were quicker to respond to larger numbers with their left hand and to smaller numbers with their right hand (Dehaene, 1997 Expt 7), furthermore the extent of the difference from the French group was influenced by the length of time spent in the West; the longer the time spent in West the greater the similarity with the French group. This supports the suggestion that poor performance may be expected from synaesthetes who report elaborate or counter-intuitive number forms (e.g. right to left, as some synaesthetes have reported). Some support for this line of reasoning was observed in the present study. For the arithmetic task the performance of those synaesthetes experiencing incongruent mental number forms was poorer than the rest of the group, for example AD's mean reaction times for the addition and subtraction tasks were over 2.s.d greater than the mean. This implies that there may be a more subtle distinction to be drawn between the synaesthesia and controls groups. If this is the case then it should be possible to devise an objective test that makes a more direct assessment of the impact that synaesthetes mental number forms are having and thus a clearer distinction between the two groups may arise.

The Dehaene (1997) study may also help to explain one fundamental question that needs to be addressed, which is why so many synaesthetes report experiencing problems with numbers and calculation. The longer the Iranian subjects in Dehaene's study had spent in a western culture, with exposure to a left to right approach to processing letters and numbers, the weaker the reverse SNARC effect observed. As mentioned earlier, synaesthetes may have struggled with mathematics when younger, perhaps owing to differing number forms and have subsequently developed strategies to cope with their difficulties.

What is clear is that any potential differences between synaesthetes and controls are too subtle to be evaluated by asking the broad types of question that were used in the questionnaire and there is likely to be a wide array of mathematical abilities amongst synaesthetes. This was highlighted in a recent study by Rich et al (2005) which showed a clear division between synaesthetes. Participants were asked to report strengths and weaknesses for a range of cognitive abilities; in line with other reports more synaesthetes reported weaknesses in mathematics than controls *but* synaesthetes were also more likely to report mathematics as a strength. This discrepancy may be because the broad concept of mathematical abilities leads different participants to think about different types of strengths and weaknesses – for some it may have been interpreted as memory for numbers as opposed to calculation abilities? Alternatively, it may be that some synaesthetes *are* poorer than controls at maths and other synaesthetes *are* better, dependant on the type of synaesthesia, or number form, they experience.

What is clear is that not all synaesthetes display the set of cognitive weaknesses that have been attributed to them and that there is still much to be understood about this fascinating area of research.

5 REFERENCES

Alexander, D., & Money, J. (1966). Turner's syndrome and Gerstmann's syndrome: Neuropsychologic comparisons. Neuropsychologia, 4, 265-273.

Ardila, A., Concha, M., & Rosselli, M. (2000). Angular gyrus syndrome revisited: Acalculia, finger agnosia, right-left disorientation and semantic aphasia. Aphasiology, 14, 743-754.

Armel, K. C., & Ramachandran, V. S. (1999). Acquired synaesthesia in retinitis pigmentosa. Neurocase, 5, 293-296.

Ashcraft, M.H. (1995). Cognitive psychology and simple arithmetic: A review and summary of new directions. Mathematical Cognition, 1, 3-34.

Atkinson, J., Campbell, F. W., & Francis, M. R. (1976). The magic number 4+-0: A new look at visual numerosity judgements. Perception, 5, 327-334.

Baron-Cohen, S., Harrison, J., Goldstein, L. H., & Wyke, M. (1993). Coloured speech perception: Is synaesthesia what happens when modularity breaks down? Perception, 22, 419-426.

Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., & Bolton, P. (1996). Synaesthesia: Prevalence and familiality. Perception, 25, 1073-1079.

Baron-Cohen, S., Wyke, M. A., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. Perception, 16, 761-767.

Bender, M.B. (1952). Disorders of perception. Springfield, IL: Charles C. Thomas.

Bisiach, E., & Luzzatti, C. (1978). Unlateral neglect of representational space. Cortex, 14, 129-133.

Butterworth, B., Grana, A., Piazza, M., Girelli, L., Price, C., & Skuse, D. (1999). Language and the origins of number skills: Karyotypic differences in Turner's syndrome. Brain and Language, 69, 486-488.

Calkins, M. W. (1895). Synaesthesia. American Journal of Psychology, 7, 90-107.

Cipolotti, L., & Butterworth, B. (1995). Toward a multiroute model of number processing: Impaired number transcoding with preserved calculation skills. Journal of Experimental Psychology: General, 124, 375-390.

Cochon, F., Cohen, L., van de Moortele, P. F., & Dehaene, S. (1999). Differential contributions of the left and right inferior parietal lobules to number processing. Journal of Cognitive Neuroscience, 11, 617-630.

Collins, M. (1929). A case of synaesthesia. Journal of General Psychology, 2, 12-27.

Critchley M. (1953) The parietal lobes. New York: Hafner.

Cytowic, R. E., & Wood, F. B. (1982a). Synaesthesia II: Psychophysical relations in the synaesthesia of geometrically shaped taste and colored hearing. Brain and Cognition, 1, 36-49.

Cytowic, R. E. (1989). Synaesthesia: A Union of the Senses. New York: Springer.

Cytowic, R. E. (1993). The Man who Tasted Shapes. London: Abacus Books.

Cytowic, R. E. (2002). Synaesthesia: A Union of the Senses (2nd Edition). Cambridge, MA: MIT Press.

Dagenbach, D., & McCloskey, M. (1992). The organisation of arithmetic facts in memory: Evidence from a brain-damaged patient. Brain and Cognition, 20, 345-366.

Day, S. (2004) Trends in Synesthetically Colored Graphemes and Phonemes

Dehaene, S. (1992). Varieties of numerical abilities. Cognition, 44, 1-42.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and numerical magnitude. Journal of Experimental Psychology: General, 122, 371-396.

Dehaene, S. and Cohen, L. (1995) Towards an anatomical and functional model of number processing. Mathematical Cognition 1, 83–120

Dehaene, S., & Cohen, L. (1997). Cerebral pathways for calculation: Double dissociation between rote and quantitative knowledge of arithmetic. Cortex, 33, 219-250.

Delazer, M., & Benke, T. (1997). The arithmetic facts without meaning. Cortex, 33, 697-710.
Deloche, G., and Seron, X. (1982). From one to 1: An analysis of a transcoding process by means of neuropsychological data. Cognition 12: 119–149.

Dixon, M. J., Smilek, D., Cudahy, C., & Merikle, P. M. (2000). Five plus two equals yellow. Nature, 406, 365.

Farrell W. (1979). Coding left and right. Journal of Experimental Psychology: Human Perception and Performance 5, 42-51.

Fias, W., Reynvoet, B., & Brysbaert, M. (2001). Are Arabic numerals processed as pictures in a Stroop interference task? Psychological Research 65, 242-249.

Fias, W., Lammertyn, J., Reynvoet, B., Dupont, P., & Orban, G. (2003). Parietal representation of symbolic and nonsymbolic magnitude. Journal of Cognitive Neuroscience., 15, 47-56.

Fink, G. R., Marshall, J. C., Shah, N. J., Weiss, P. H., Halligan, P. W., Grosse-Ruyken, M., Ziemons, K., Zilles, K., & Freund, H. J. (2000). Line bisection judgments implicate right parietal cortex and cerebellum as assessed by fMRI. Neurology, 54, 1324-1331.

Flournoy, T. (1893). Des phemomenes de synopsie. Paris: Alcan.

Galton, F. (1880a). Statistics on mental imagery. Mind, 5, 301-318.

Galton, F. (1880b). Visualised numerals. Nature, 21, 494-495.

Galton, F. (1881). Visualised numerals. Journal of the Anthropological Society, 10, 85-102.

Geary, D. C. (2004). Mathematics and learning disabilities. Journal of Learning Disabilities, 37, 4-15.

Gertsmann, J. (1940). Syndrome of finger agnosia, disorientation for right and left, agraphia and acalculia. Archives of Neurology and Psychiatry, 44, 398-408.

Gerstmann J. (1957). Some notes on the Gerstmann syndrome. Neurology, 7: 866–9.

Gevers, W., Reynvoet, B., & Fias, W. (2003). The mental representation of ordinal sequences is spatially organized. Cognition, 87, B87-B95.

Ginsberg, L. (1923). A case of synaesthesia. American Journal of Psychology, 34, 582-589.

Gold, M., Adair, J.C., Jacobs, D.H. & Heilman, K.M. (1995) Right-left confusion in Gerstmann's syndrome: a model of body centered spatial orientation. Cortex 31 (2) :267-83.

Grossenbacher, P. G., & Lovelace, C. T. (2001). Mechanisms of synaesthesia: Cognitive and physiological constraints. Trends in Cognitive Sciences, 5, 36-41.

Harrison, J. E., & Baron Cohen, S. (1997). Synaesthesia: An introduction. In S. Baron-Cohen & J. E. Harrison (Eds.), Synaesthesia: Classic and Contemporary Readings . Oxford: Blackwell.

Hartman, A. M., & Hollister, L. E. (1963). Effect of mescaline, lysergic acid diethylamide and psilocybin on color perception. Psychopharmacolgia, 4, 441-451.

Hecaen, H., Angelergues, R., & Houllier, S. (1961). Les varietes cliniques des acalculies au cour des lesions retrolandiques: Approch statistique du probleme. Revue Neurologique, 105, 85-103.

Henschen (1925) Klinische und anatomische Beitrage zur Pathologie des Gehirns, Almquist and Wiksells, Upsala, 1890 i-vii Arch f. Psychiat. lxxv p630

Isaacs, E. B., Edmonds, C. J., Lucas, A., & Gadian, D. G. (2001). Calculation difficulties in children of very low birth weight. Brain, 124, 1701-1707.

Locke, J. (1690) An essay concerning human understanding, Book 3. London: Basset

Jung, R. E., Yeo, R. A., Sibbitt, W. L., Ford, C. C., Hart, B. L., & Brooks, W. M. (2001). Gertsmann syndrome in systemic lupus erythematosus: Neuropsychological, neuroimaging, and spectroscopic findings. Neurocase, 7, 515-521.

Kinsbourne, M., & Warrington, E. K. (1963). The developmental Gerstmann syndrome. Archives of Neurology, 8, 490-501.

McNeil, J.E., & Warrington, E.K. (1994). A dissociation between addition and subtraction within written calculation. Neuropsychologia, 32, 717–728.

McCloskey, M. (1992). Cognitive mechanisms in numerical processing: Evidence from acquired dyscalculia. Cognition, 44, 107-157.

McCloskey, M., Caramazza, A., & Basili, A. (1985). Cognitive mechanisms in number processing and calculation: Evidence from dyscalculia. Brain and Cognition, 4, 171-196.

Mattingley, J. B., Driver, J., Beschin, N., & Robertson, I. H. (1997). Attentional competition between modalities: Extinction between touch and vision after right hemisphere damage. Neuropsychologia, 35, 867-880.

Mattingley, J. B., Rich, A. N., & Bradshaw, J. L. (2001). Unconscious priming eliminates automatic binding of colour and alphanumeric form in synaesthesia. Nature, 410, 580-582.

Mayer, E., Martory, M.-D., Pegna, A. J., Landis, T., Delavelle, J., & Annoni, J.-M. (1999). A pure case of Gerstmann syndrome with a subangular lesion. Brain, 122, 1107-1120.

Mazzocco, M. M. M. (2001). Math learning disability and math LD subtypes: Evidence from studies of Turner syndrome fragile X syndrome, and neurofibromatosis type 1. Journal of Learning Disabilities, 34 (6): 520-533.

Mills, C. B., Boteler, E. H., & Oliver, G. K. (1999). Digit synaesthesia: A case study using a stroop-type test. Cognitive Neuropsychology, 16, 181-191.

Moyer, R. S., & Landauer, T. K. (1967). Time required for judgements of numerical inequality. Nature, 215, 1519-1520.

Nelson, H. E. & O'Connell, A. (1978). Dementia: the estimation of premorbid intelligence levels using the new adult reading test. Cortex 14, 234–244.

Nuerk, H.C., Weger, U., & Willmes, K. (2001). Decade breaks in the mental number line? Putting the tens and units back in different bins. Cognition, 82, B25-B33.

Odgaard, E.C., Flowers, J.H. and H.L. Bradman. (1999). An Investigation of the Cognitive and Perceptual Dynamics of a Color-Digit Synaesthete. Perception, 28: 651-664.

Ofte, S. J. & Hugdahl, K. (2002). Rightleft Discrimination in Male and Female, Young and Old Subjects. Journal of Clinical and Experimental Neuropsychology, 24, 82-92

Paulesu, E., Harrison, J., Baron-Cohen, S., Watson, J. D. G., Goldstein, L., Heather, J., Frackowiak, R. S. J., & Frith, C. D. (1995). The physiology of coloured hearing: A PET activation study of colour-word synaesthesia. Brain, 118, 661-676.

Patrick, G. T. W. (1893). Number-forms. Popular Science Monthly, February, 506.

Peabody, C. (1915). Certain further experiments in synaesthesia. American Anthropologist, 17, 143-155.

Phillips, D. E. (1896-97). Genesis of number-forms. American Journal of Psychology, 506-527.

Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia - A window into perception, thought and language. Journal of Consciousness Studies, 8, 3-34.

Restle, F. (1970) Theory of serial pattern learning: Structural trees. Psychological Review, 77, 481-495

Rich, A. N., Bradshaw, J. L. & Mattingley, J. B. (2005) A systematic, large-scale study of synaesthesia: implications for the role of early experience in lexical-colour associations Cortex

Rovet, J., Szekely, C., & Hockenberry, M.-N. (1994). Specific arithmetic calculation deficits in children with Turner syndrome. Journal of Clinical and Experimental Neuropsychology, 16, 820-839.

Seron, X., Pesenti, M., Noel, M.-P., Deloche, G., & Cornet, J. A. (1992). Images of numbers, or "when 98 is upper left and 6 sky blue". Cognition, 44, 159-196.

Shalev, R. S., & Gross-Tsur, V. (2001). Developmental dyscalculia. Pediatric Neurology, 24(5), 337-342

Shepard, R. N., Metzler, J. (1971). Mental Rotation of Three-Dimensional Objects. Science, Feb., 701-703.

Simner, J., Mulvenna, C., Sagiv, N., Tsakanikos, E., Witherby, S. A., Fraser, C., Scott, K., & Ward, J. (in press). Synaesthesia: The prevalence of atypical cross-modal experiences. Perception.

Simon, T.J., Peterson, S., Patel, G., & Sathian, K. (1998). Do the magnocellular and parvocellular visual pathways contribute differentially to subitizing and counting? Perception & Psychophysics, 60, 451-464.

Spalding, J. M. K., & Zangwill, O. L. (1950). Disturbance of number-form in a case of brain injury. Journal of Neurology, Neurosurgery and Psychiatry, 13, 24-29.

Suresh, P.A. & Sebastian, S. (2000) Developmental Gerstmann's syndrome: a distinct clinical entity of learning disabilities. Pediatric Neurology 22 (4): 267-78

Taves, E. H. (1941). Two mechanisms for the perception of visual numerousness. Archives of Psychology, 37, 1-47.

Trick, L. M., & Pylyshyn, Z. W. (1993). What enumeration studies can show us about spatial attention: Evidence for limited capacity preattentive processing. Journal of Experimental Psychology: Human Perception and Performance, 19, 331-251.

Turconi & Seron (2002) Dissociation between order and quantity meanings in a patient with Gerstmann syndrome. Cortex 38, 911-914

Udwin, O., Davies, M. and Howlin, P. (1996) A longitudinal study of cognitive and education attainment in Williams syndrome. Developmental Medicine and Child Neurology, 38, 1020-29.

Vuilleumier, P., Ortigue, S., & Brugger, P. (2004). The number space and neglect. Cortex, 40, 399-410.

Ward, R., Goodrich, S. J. & Driver, J. (1994). Grouping reduces visual extinction: Neuropsychological evidence for weight-linkage in visual selection. Visual Cognition, 1, 101-129.

Ward, J., & Simner, J. (2005). Is synaesthesia an X-linked dominant trait with lethality in males? Perception, 34, 611-623

Wheeler, R. H., & Cutsforth, T. D. (1921). The number forms of a blind subject. American Journal of Psychology, 32, 21-25.

Wingard, E. M., Barrett, A. M., Crucian, G. P., Doty, L., & Heilman, K. M. (2002). The Gerstmann syndrome in Alzheimer's disease. Journal of Neurology, Neurosurgery and Psychiatry, 72, 403-405.

Wollen, K.A. & Ruggiero, F.T. (1983) Coloured-letter synaesthesia. Journal of Mental Imagery, v7, i2, p83-86.

Zorzi, M., Priftis, K., & Umilta, C. (2002). Brain damage - Neglect disrupts the mental number line. Nature, 417, 138-139.

6 APPENDIX A – QUESTIONNAIRES

SYNAESTHESIA QUESTIONNAIRE

Initials: ______________________ **Age:**______________ **Sex:** **Male / Female**

(1) Are you left or right handed?

LEFT RIGHT AMBIDEXTROUS

(2) Please match the triggers on the left with experiences on the right. For instance, if you experience colours in response to numbers then draw a line in between 'numbers' (left) and 'colours' (on right), and so on. There is no need to draw lines between the same things (e.g. colours – colours) as this is assumed to be true of everyone.

TRIGGERS	**EXPERIENCES**
Letters of alphabet	Colours
English words	Shapes
Foreign words	Tastes
Peoples names	Smells
Addresses/places	Pains/touches
Numbers	Noises
Days of week	Patterns
Months of year	Flashes
Voices	Music
Pains/touches	Movements
Body postures	
Music (instrumental)	
Noises	
Smells	
Tastes	
Colours	
Shapes	
Patterns	

(2) Do these experiences have specific locations (e.g. on your body, on words or objects in the environment, in front of your eyes) or not (e.g. they feel as if they are in 'your minds eye')? Please describe.

____

____

____

____

____

(4) To the best of your knowledge have you always had these sensations?

YES NO

If YES – at what age did you become aware that other people did not have the same sensations as you?

____

If NO – at what age did they arise and was there a triggering incident?

____

____

(5) Can you remember having any other forms of synaesthesia that you no longer have?

YES NO

If YES – then please describe them.

____

____

(6) Does anyone in your family experience similar things?

YES NO DON'T KNOW

If YES – please describe their relationship to you (father, cousin etc.) and the effects that they experience?

____

____

(7) Do you, or anyone in your family, have a history of epilepsy or other neurological conditions?

YES NO

If YES – please give details

____

—

____

—

(8) Are the sensations that you experience enhanced or reduced by the following...

STRESS	Enhanced	No difference	Reduced	Don't know
ALCOHOL	Enhanced	No difference	Reduced	Don't know
SLEEPINESS	Enhanced	No difference	Reduced	Don't know
CAFFEINE	Enhanced	No difference	Reduced	Don't know
HAPPINESS	Enhanced	No difference	Reduced	Don't know
DEPRESSION	Enhanced	No difference	Reduced	Don't know

(9) Do the sensations that you have to particular things change over time or are they fixed (e.g. if the word 'book' is red then is it always red, and always has been)?

FIXED VARIABLE DON'T KNOW

(10) Do you ever have the feeling that you have lived through this moment before (déjà vu)?

Never Very rarely Occasionally Quite often Very often

(11) Do you feel that you have been held back in life because of the sensations you experience?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(12) Do you think that you are very fussy about keeping things in their right place (e.g. around the home)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(13) Do you find that you often get left and right confused?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(14) Do you have (or have you ever had) problems with numbers and/or calculation?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(15) Do you have (or have you ever had) problems with reading and spelling?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If YES, then were you ever formally assessed for dyslexia? ______________________________

(16) Do you think about the letters of the alphabet being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

(17) Do you think about numbers being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

(18) Do you think about days or months being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

(19) Do you think about numbers and/or letters having personalities or genders?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then list them on a separate sheet.

(20) There are certain letters that I like or dislike much more than others.

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If so then please note the ones that you like: = ________________________________

And the ones you dislike: = ____

(21) Do you find that objects appear to move when you look at them?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(22) When you look at an object and then look away, do you find that the image of the object can persist or duplicate?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(23) If you look at a moving object does it appear to leave a visual trail behind it?

Never Very rarely Sometimes Often Almost always

(24) Do colours appear to spread or pour out of things that you look at?

Never Very rarely Sometimes Often Almost always

(25) Do objects appear to have visual halos around them?

Never Very rarely Sometimes Often Almost always

If YES, then are the halos/auras coloured? ________________________________

(26) Do objects ever appear to shrink or expand in size when you look at them?

Never Very rarely Sometimes Often Almost always

(28) Do you ever feel as if you were standing aside and watching yourself?

Never Very rarely Sometimes Often Almost always

(29) Does it ever feel that some part of your body was disconnected or somehow didn't belong to the rest of your body?

Never Very rarely Sometimes Often Almost always

(30) Does it ever feel that time has come to a stand still?

Never Very rarely Sometimes Often Almost always

(31) I think that I have a superior sense of smell?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(32) I think that I have a superior sense of taste?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(33) I think that I have a superior sense of touch?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(34) I think that I might have 'perfect/absolute pitch' (i.e. you can immediately identify a musical note)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(35) Do you have (or have you ever had) any kind of hearing impairment?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If yes, then please give details: ____

(36) Do you have (or have you ever had) any problems with colour vision?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(37) Do you think that you use sensory imagery to remember things (e.g. your memories are very visual, tactile or whatever)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(38) Do you ever feel overwhelmed or bombarded by the sensations that you experience?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(39) Briefly describe your earliest ever memory? How old do you think you were when this event happened?

____

__

____

__

(40) My dreams contain very vivid experiences and sensations.

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If SO: Do they contain: vision, smell, taste, touch/pain, sounds (circle as many as apply)

(41) I often have recurring dreams.

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

(42) I often have intrusive memories of the past that come to mind <u>spontaneously</u> (they can be trivial or serious).

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

Part 2: Response to Specific Words

There is a 3 page list of words attached. The words are listed in two separate columns. I you would like you to consider your response to each of the words in turn. The words come from different categories (e.g. letters, numbers, people, places) and some may not be familiar to you. For each item, I'd like you to do two things...

(1) In the column marked '0-9', please indicate on a 0 to 9 scale how intense your synaesthetic experience is (this should also relate to how confident you are that you are experiencing one). If you experience nothing at all, then mark the column 0. If it is very intense then mark it 9. Fell free to use the entire range of numbers in between, but don't worry if you use some ratings more than others – so long as though it is your best judgement. Some people find that the intensity never varies, in which case you are not expected to fill this bit in. Here is a summary of the scale....

0	1	2	3	4	5	6	7	8	9
no experience							very intense & very confident		

(2) In the column marked 'Description', I would like you to describe succinctly and to the best of your ability the nature of your synaesthetic experience (e.g. deep blue). If you don't experience anything at all then just put a dash in the column.

<u>Many thanks for your time.</u>

	0-9	Description		0-9	Description
a			Monday		
b			Tuesday		
c			Wednesday		
d			Thursday		
e			Friday		
f			Saturday		
g			Sunday		
h			January		
i			February		
j			March		
k			April		
l			May		
m			June		
n			July		
o			August		
p			September		
q			October		
r			November		
s			December		
t			Margaret Thatcher		
u			Michael Jackson		
v			Elvis Presley		
w			Adolf Hitler		
x			Marilyn Monroe		
y			Elizabeth II		
z			David Beckham		
1			Tony Blair		
2			Terry Wogan		
3			Michael Caine		
4			Scotland		
5			Italy		
6			Spain		
7			Japan		
8			Canada		
9			Brazil		
0			France		
ked			Ireland		

	0-9	Description		0-9	Description
bem			Germany		
shid			Russia		
boak			USA		
snite			window		
hance			coffee		
dringe			manner		
squate			potato		
doop			plea		
nar			elbow		
alcohol			radio		
night			thought		
episode			feather		
pig			principle		
hospital			valour		
thing			satire		
marriage			crisis		
moment			realm		
funnel			school		
mercy			summer		
pact			monkey		
clue			theory		
length			village		
spider			gravity		
character			hotel		
hand			drum		
axe			woe		
audience			idea		
deed			slope		
fire			plane		
analogy			fact		
wrath			tobacco		
pill			purpose		
elephant			tribute		
mother			onion		
bonus			irony		
member			treason		
effort			picture		
miracle			system		
tractor			opinion		
letter			student		
gravy			cart		
quality			pupil		
attitude			church		
concept			folly		
dogma			battle		
wheat			session		

CONTROL QUESTIONNAIRE

Age:________________ **Sex: Male / Female**

1. Are you left or right handed LEFT RIGHT AMBIDEXTROUS

2. Do you ever have the feeling that you have lived through this moment before (déjà vu)?
Never Very rarely Occasionally Quite often Very often

3. Do you think that you are very fussy about keeping things in their right place (e.g. around the home)?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

4. Do you find that you often get left and right confused?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

5. Do you have (or have you ever had) problems with numbers and/or calculation?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

6. Do you have (or have you ever had) problems with reading and spelling?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If YES, then were you ever formally assessed for dyslexia?

____

7. Do you think about the letters of the alphabet being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

8. Do you think about numbers being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

9. Do you think about days or months being arranged in a specific pattern in space (e.g. in a line, or circle, or other)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then please try to draw this on a separate sheet.

10. Do you think about numbers and/or letters having personalities or genders?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If you answered 'agree' or 'strongly agree' then list them on a separate sheet.

11. There are certain letters that I like or dislike much more than others.

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If so then please note the ones that you like: =

____

And the ones you dislike: =

____

12. Do you find that objects appear to move when you look at them?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

13. When you look at an object and then look away, do you find that the image of the object can persist or duplicate?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

14. If you look at a moving object does it appear to leave a visual trail behind it?

Never Very rarely Sometimes Often Almost always

15. Do colours appear to spread or pour out of things that you look at?

Never Very rarely Sometimes Often Almost always

16. Do objects appear to have visual halos around them?
Never Very rarely Sometimes Often Almost always

If YES, then are the halos/auras coloured? ________________________________

17. Do objects ever appear to shrink or expand in size when you look at them?
Never Very rarely Sometimes Often Almost always

18. Do two-dimensional drawings or pictures give an illusion of being 3D?
Never Very rarely Sometimes Often Almost always

19. Do you ever feel as if you were standing aside and watching yourself?
Never Very rarely Sometimes Often Almost always

20. Does it ever feel that some part of your body was disconnected or somehow didn't belong to the rest of your body?
Never Very rarely Sometimes Often Almost always

21. Does it ever feel that time has come to a stand still?
Never Very rarely Sometimes Often Almost always

22. Do you think that you have a superior sense of smell?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

23. Do you think that you have a superior sense of taste?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

24. Do you think that you have a superior sense of touch?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

25. Do you think that you might have 'perfect/absolute pitch' (i.e. you can immediately identify a musical note)?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

26. Do you have (or have you ever had) any kind of hearing impairment?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If yes, then please give details:

____

27. Do you have (or have you ever had) any problems with colour vision?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If yes, then please give details:

____

28. Do you think that you use sensory imagery to remember things (e.g. your memories are very visual, tactile or whatever)?

Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

29. Do you ever feel overwhelmed or bombarded by the sensations that you experience?
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

30. Briefly describe your earliest ever memory? How old do you think you were when this event happened?

____

____

_

31. My dreams contain very vivid experiences and sensations.
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

If SO: Do they contain: vision, smell, taste, touch/pain, sounds (circle as many as apply)

32. I often have recurring dreams.
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

33. I often have intrusive memories of the past that come to mind spontaneously.
Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree

7 APPENDIX B – SUBITIZE STIMULI