Investigations of Synesthesia

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ABSTRACT

This thesis explores various aspects of the phenomenon of synesthesia where stimulation of one sense modality (such as in audition or vision) evokes sensations in another modality.

Chapter 1 presents an overview of the range of synesthetic phenomena and outlines the questions explored in this thesis. Chapter 2 examines the diagnosticity and utility of four tests of genuineness (TOG) based on the new method implemented in the Synesthesia Battery (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). The TOG were found to adequately differentiate between groups of synesthetes and controls. New cut off scores for the tests were derived using signal detection theory (SDT) and the derivation of subjective signal strength (d'). Diagnosticity of the tests at the individual level was found to vary depending on the test and was not a function of the new method but rather the phenomenology of the type of synesthesia being examined. The new method produces results that are consistent with the traditional testing method and therefore both the new method and the Synesthesia Battery which implements it, are useful new tools to aid future researchers.

Chapter 3 focuses on a previous claim by Day (2005) that colours are matched between graphemes based on their shape similarity. Using the data from the TOG for graphemes, we found that synesthetic colour associations tend to be shared between graphemes that are different category (letter - number) pairs rather than same category (letter – letter) pairs. This suggests a categorical transfer of colour between graphemes rather than colour transfer based simply on shared early visual features.

Chapter 4 investigates the nature of the synesthetic Stroop effect. We administered both the synesthetic Stroop screen colour naming experiment and the synesthetic Stroop associated colour naming experiment to synesthetes and non-synesthetes. In both experiments we administered unique stimulus ensembles to each participant. Ensembles comprised graphemes for which the participants had strong colour match consistency in the TOG for graphemes. This differed from previous designs which administered synesthetes' stimulus ensembles to controls. Synesthetic Stroop effects were elicited in non-synesthetic individuals in both experiments. Utilising the unique stimulus ensembles for individual participants enabled the first comparison between synesthetes and non-synesthetes in the associated colour naming paradigm. No significant difference in effects were found between the groups. In the screen colour

naming experiment, Stroop interference effects were found to correlate with the colour match consistency score in the grapheme TOG. These results suggest that the synesthetic stroop effect is not unique to synesthesia, and that Stroop effects likely reflect the strength of paired stimulus dimensions. This interpretation was supported by our examination of a single synesthete, for whom projected synesthetic colour is elicited by both graphemes and geometric shapes, and of which, the graphemes synesthetic colour is reported to be stronger. Consistent with the self report, we found that synesthetic Stroop effects were elicited by geometric shape inducers, and these effects were significantly weaker than those elicited by grapheme inducers. This held for both types of Stroop test.

Chapter 5 describes two cases of poly-modal and multi-concurrent synesthesia. They challenge current theoretical accounts of the condition, particularly the localised cross-wired hypothesis.

Chapter 6 reports on the conduct of a preliminary inquiry into the relationship between absorbed attention and synesthesia. Using the modified Tellegen Absorption Scale (MODTAS) (Jamieson, 2005) we found that synesthetes report significantly higher levels of absorbed attention in everyday activities. We make some speculative suggestions as to why this might be the case and propose future inquiries.

Chapter 7 investigates the multisensory nature of synesthesia. We administered the sound induced flash and fusion illusions (Shams, Kamitani, & Shimojo, 2000) to synesthetes and controls. Synesthetes did not report the illusion any more often than control subjects. We discuss the assumptions of the research question and general limitations of the study.

Chapter 8 discusses the implications of the research presented in this thesis as well as its limitations. Recommendations for future research that include longitudinal and developmental investigations are also made.

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All research complies with the ethics guidelines set by the University of Sydney:

Project title: Understanding the perceptual and visual basis of synesthesia

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1. SYNESTHESIA DEFINED AND DESCRIBED

"Synesthesia is a little like an octopus isn't it... reaching its tentacles out into so many different areas".
(Cytowic, 1993)

1.1. Introduction

Synesthesia - from the Greek: syn = together + aesthesia = sensation (Sagiv, 2005), is a term that has been used to describe an extensive variety of phenomena. The term synesthesia is associated with a large and diverse - but phenomenologically similar - set of experiences. It describes:

- a collection of spontaneously arising, cross-sensory experiences which occur under absorbed states of consciousness, such as in meditation (Walsh, 2005). In this thesis we use the term 'spontaneous synesthesia' to describe these phenomena.
- a collection of spontaneously arising, cross-sensory experiences which occur under hallucinogenic drugs (Stuckey, Lawson, & Luna, 2005; Walsh, 2005). In this thesis we use the term 'induced synesthesia' to describe these phenomena.
- principled translation between the senses. Several studies have shown that there may be simple sensory principles that unite information from different senses into a coherent experience. For example, Marks (1982a, 1982b, 1989) has shown that lightness and pitch are often correlated by individuals so that bright colour is associated with high pitched tones. Spector & Maurer, (2008) have also described correspondences between shape and colour in infants. For clarity in this thesis, we shall term these types of synesthesia, 'inter-sensory translations' or 'inter-sensory correspondences'.
- the rewiring of the brain which results from injury or loss, particularly in blindness (Proulx, 2010). In this thesis we use the term 'acquired synesthesia' to describe these phenomena.
- metaphorical correspondences between two stimuli. Metaphors which describe these correspondences include loud shirts, sharp cheese (Ramachandran & Hubbard, 2001a), bright sneezes and dark coughs (Marks, 1982). In art and music the term is more frequently used to describe aesthetically pleasing or carefully construed correspondences between different media (Ox, 1999). In

this thesis we use the term 'synesthetic metaphor' to describe these correspondences.

- a cluster of consistent correspondences or associations between the senses (Cytowic, 1993) or within a single sense (Hubbard, Arman, Ramachandran, & Boynton, 2005). For example, the consistent pairing of the number three with yellow or the evocation of colours or shapes when listening to music. These correspondences are claimed to be permanent and enduring from childhood. We use the term 'idiopathic synesthesia' to describe these phenomena. The term 'developmental synesthesia' has also been used to describe these synesthesias as recent studies have provided some evidence for a neuroanatomical basis of the condition (Rouw & Scholte, 2007; Weiss & Fink, 2009). With advances in neuroimaging, genetic analysis and general progress in the field, the term idiopathic may be at some risk of becoming obsolete and may well be replaced by more descriptive neurological terms.

A key question of research in synesthesia is whether or not these diverse phenomena share the same underlying aetiology. The focus of this thesis is the exploration of idiopathic synesthesia in the context of what it might share with – and what might differentiate it from;

- the other synesthesias in the family.
- simple associations between objects and senses common to all individuals.

1.2. Accurate Identification of Idiopathic Synesthesia

If the term synesthesia wasn't broad enough, researchers are also faced with an overwhelmingly large number of different types of idiopathic synesthesia - many of which are quite uncommon. According to Day (2010) there are 61 different varieties.

1.2.1. Types of Idiopathic Synesthesia

Table 1-1 shows the most common types of synesthesia and their reported incidence in a self referred population (Day, 2007). According to Day (2007) 49% of self-referred synesthetes who report one type of synesthesia also report other types of synesthesia (as such Table 1-1 adds to greater than 100%). Simner et al., (2006) report that synesthetes who have other forms of synesthesia (e.g. taste/shape) are significantly more likely to also have coloured days, compared to people who do not. In their university sample, "14 synesthetes (2.8%) exhibited weekday day colour synesthesia, making it the most common overall, and constituting at least one manifestation in 64% of synesthetes". Grapheme to colour synesthesia occurred in only 45% of the total pool of synesthetes. Most importantly they found only 9 of a total possible 128 different manifestations. This is only 7% of the possible total forms of synesthesia. In addition, the vast majority of these had colour as the synesthetic concurrent (i.e. 77% of the 9 different variants, and 95% of all instances found). The Simner et al., (2006) paper is critical for future research in synesthesia because the findings suggest that the systematic study of many forms of synesthesia may not be amenable to group based studies.

Type and incidence		Type and incidence		Type and incidence	
Graphemes -> Colour	67%	Sound -> Taste	6%	Vision -> Smell	1%
Time Units -> Colour	24%	Pain -> Colour	6%	Orgasms -> Colour	1%
Mus. Sounds -> Colour	19%	Personalities -> Colour	6%	Vision -> Touch	1%
Gen. Sounds -> Colour	15%	Touch -> Colour	4%	Emotion -> Colour	1%
Phonemes -> Colour	10%	Sound -> Touch	4%	Smell -> Touch	1%
Mus. Notes -> Colour	10%	Temperatures -> Colour	3%	Smell -> Sound	1%
Odours -> Colour	7%	Vision -> Taste	2%	Sound -> Kinetics	1%
Tastes -> Colour	7%	Sound -> Smell	2%	Sound -> Temp.	1%
		Vision -> Sound	2%	Taste -> Touch	1%

Table 1-1. Incidence of synesthesia – Day (2007) Inducer -> concurrent pairs

1.2.2. Incidence of Idiopathic Synesthesia

Early estimates of synesthesia ranged from 1 in 4 (Calkins, 1895; Domino, 1989); 1 in 200 (Ramachandran and Hubbard 2001a), and 1 in 25,000 to 100,000 (Cytowic, 1993, 1997). The most commonly cited study shows a prevalence of "at least 1 in 2000" with a female : male ratio of 5.5 : 1 (Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996). An Australian investigation reports a prevalence of 2.4% and a female bias of 6.2 : 1 (Rich, Bradshaw, & Mattingley, 2005). Both these studies based their estimates on the number of respondents to newspaper advertisements, together with those newspapers' circulation figures. More recently however the apparent female bias has lowered to 2 : 1 (Simner et al., 2005). This was derived from a university student population.

The most comprehensive study to date assessed a large number of people (N = 1690) and verified the reports of synesthesia with objective tests for consistency over time

(Simner et al., 2006). The prevalence for synesthesia reported in the study was 4.4%, with a female : male ratio of 1.1 : 1, which showed no significant sex bias.

Synesthesia tends to run in families. Parents and children often have different forms of synesthesia and even when similar forms of synesthesia are expressed from parent to child these are still influenced by other factors (Barnett, Finucane et al., 2008). The prevalence of synesthesia among biological relatives of synesthetes surveyed by (Rich et al., 2005) was found to be much higher than that estimated for the general population with 36% reporting at least one relative with synesthesia. One of the difficulties in estimating the incidence of synesthesia accurately is the fact that idiopathic synesthesia is not a condition which creates difficulties for the person who experiences it. This may lead to under reporting.

1.2.3. Terminology and Taxonomy

The family of idiopathic synesthesias is broad. Synesthesia research suffers from constantly shifting characterisations of the definitional terms used. This results in several problems. The most significant is that generalising from one study to the next can be difficult and the ability to draw appropriate conclusions from published results of experiments can be diminished. For many types of synesthesia no taxonomic classification exists, this includes synesthesias in which experiences of shape as well as colour are evoked. Poor or lacking taxonomy also makes the creation of stable methodological designs with testable hypotheses difficult.

Within the class of synesthesias evoked from language, there is a different problem. There are many overlapping terminologies and taxonomies. For instance, the following terms can be used to describe individuals who experience or associate colours with language units:

- Colour grapheme / chromatic graphemic synesthetes (Dixon & Smilek, 2005; Herrnberger et al., 2002; Hubbard et al., 2005; Paulesu et al., 1995);
- Colour lexical synesthetes (Rich et al., 2005)
- Coloured hearing synesthetes (Beeli, Esslen, & Jancke, 2008; Paulesu, Harrison, Baron-Cohen, Watson, & et al., 1995)
- Auditory colour synesthetes (Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2006),
- Auditory visual synesthetes (Asher et al., 2009; Goller, Otten, & Ward, 2009)

Each of these terms implies a slightly different relationship between the sensory modality which processes synesthesia (hearing or vision) and the unit of language (phoneme or grapheme for example) that is thought to induce it. It is by no means clear that these different classifications relate to substantial differences between the language units or that they are mutually exclusive. For example, do all those who experience colours from language units experience synesthesia when the word or letter is written and spoken? Is one a stronger inducer of colour than the other? Are phonemes or graphemes the primary inducer of colour, or some combination of both? Many synesthetes report that their synesthesia is evoked by linguistic units when written and spoken. Researchers do not as yet have the tools to assess these synesthetes to discern which one (if either) is primary.

We also pointed out in the previous section that 49% of self referred synesthetes report having more than one form of synesthesia. In this thesis we use the term poly-modal to describe such synesthetes. There are few case studies of poly-modal synesthetes with the vast majority of the literature focussing on those forms which have one invoking stimulus and one synesthetic response. It is also the case - and there is almost no discussion in the literature on this aspect – that an invoking stimulus may create more than one synesthetic experience. For example, a synesthete may experience colours and personalities in relation to language (Simner & Holenstein, 2007). In this thesis we use the term multi-concurrent to describe such synesthetes.

Martino and Marks (2001) proposed that synesthesia has both 'strong' and 'weak' forms. These may occur along a continuum but they differ in prevalence, phenomenology and possibly underlying mechanisms. Strong synesthesia occurs as a perceptual phenomenon and weak synesthesia occurs as associations in language and metaphor. The classification scheme is helpful as a starting point but has not been broadly adopted by researchers or developed further. More work is required to disambiguate fully the specific characteristics.

One recent development which seems to have been readily adopted is the more consistent use of terms, 'inducers' and 'concurrents' to describe the inducing stimulus and the synesthetic percept that is reported. According to Simner et al., (2006) inducers tend to be linguistic units such as words, letters and days. Concurrents tend to be colours or shapes, though several other types of synesthesia are also reported. Typically researchers refer to what is experienced as, a 'synesthetic percept', a 'concurrent' or a 'photism'. In this dissertation we describe the inducers by name - as graphemes or music for example - and use the terms associated or concurrent to indicate the synesthetic experience – of colour or shape for example - that is produced as a result.

1.2.4. Clinical Diagnosis

The ability to distinguish one form of synesthesia from another is paramount to proper investigation of the phenomenon. In particular, researchers should be able to distinguish individuals who present with experiences of metaphorical thinking, spontaneous synesthesias, drug induced or acquired synesthesias or excellent intersensory translation ability, from those with idiopathic synesthesia. These synesthesias share many similarities in their phenomenology with the idiopathic type. It is also important these other synesthesias are not ignored for study even though some are difficult to elicit reliably in a laboratory setting. The first concern of this thesis is how improvements in the diagnosis of idiopathic synesthesia can be made and how this information might be better used in efforts to understand the phenomenon. A comprehensive review of the criteria and the tests used to diagnose idiopathic synesthesia follows.

Cytowic (1997) was the first to propose some clinical diagnostic criteria for idiopathic synesthesia and subsequently Cytowic and Eagleman (2009) have updated them. To date they are the most descriptive and widely utilised criteria, though some have more emphasis than others. In our review we examine each of the criteria and assess it against whether it is shared with other synesthesias in the family. We include examples from participants in our study to demonstrate the characteristics of each criterion. The criteria are as follows:

Synesthesia is:

- Elementary, specific and consistent

Elementary, means the presence of simple images, simple shapes and simple representations rather than elaborated imagery. This is typically found in non graphemic synesthesia such as the example cited in Cytowic (2002) for tasted shapes. There is little research on the role of elementary forms or geometric shapes in other synesthesias and particularly shapes elicited by graphemes or music.

The elementary nature of idiopathic synesthesia is shared with spontaneous and induced synesthesias. Individuals who have taken the drug mescaline report synesthetic photisms of colour and elementary shapes (Kluver, cited in (Cytowic, 2002)). In Chapter 5, we show that simple geometric forms are also evident in the synesthetic concurrents of a respected Australian synesthete artist. We also describe a synesthete participant, EL, who reports shape and other concurrents for her synesthetic inducers which include, graphemes, sounds, music and emotions. Illustrations of her colour and form concurrents for music are shown in Figure 2-43 and her texture and form concurrents to numbers are shown in Figure 5-5 where several different but elementary geometric prototypes are also evident.

Specific is understood as particular pairings of properties, e.g. a specific colour to a specific grapheme. From the point of view of the synesthetes themselves, each synesthete has a somewhat different set of eliciting stimuli and a typically idiosyncratic set of synesthetic experiences. Using a large colour vocabulary to describe the synesthetic experiences is taken by Cytowic & Eagleman (2009) and Simner et al., (2006) as an indicator of genuineness because it indicates a high degree of specificity in the colour experienced. This is a difficult proposition because the method by which these data were collected was oral/written. It may simply be the case that synesthetes are more elaborate in their verbal explanations of their associations. However, there is some evidence to suggest that synesthetes who experience colour concurrents do have enhanced colour processing (Banissy, Walsh, & Ward, 2009). It is conceivable that this would manifest in more distinctive verbal labels as well as specific experiences of colour concurrents when elicited. The specific nature of idiopathic synesthesia also seems to be shared with spontaneous or induced synesthesias. The family of shape concurrents in induced synesthesias might easily be considered to be specific in their nature and were reported by Kluver (cited in Betancourt (2007)) to be elicited specifically and consistently.

Consistent, is understood to mean consistent over time. 89% of surveyed synesthetes report having synesthesia consistently linked to specific stimuli (Rich et al., 2005). This consistency is currently the single most defining characteristic of idiopathic synesthesia as it does not appear to be shared by other family members. However, Marks (1989) has found that non-synesthetic individuals can, and do, translate sensory dimensions in consistent and reliable ways, such as equating pitch with brightness. In this respect, this aspect is not unique to idiopathic synesthesia. By far, the majority of experiences tested for consistency by researchers are those elicited by graphemes and it is usually the colour of the experience which is assessed, not any shape or texture which may also be elicited. Given that inducing stimuli can evoke more than one class of sensation, opportunities for examining the consistency of other concurrents in the diagnostic tests may have been overlooked. Testing for consistency over time is the basis of the traditional testing paradigm for the genuine presence of synesthesia (Baron-Cohen, Wyke, & Binnie, 1987).

- Automatic and involuntary

Synesthesia is difficult to suppress and not imagined. There is evidence to suggest that idiopathic synesthesia is automatic rather than a function of deliberate recall (Lupianez & Callejas, 2006). The extent to which the phenomenon is automatic is questionable as only 76% of synesthetes surveyed by Rich et al., (2005) reported that their synesthesia was not under voluntary control. 15% reported complete control over it, with 4% being able to induce the synesthesia but not prevent it.

It also seems that deliberate attention does play a role in the experience of synesthesia. In the Rich et al., (2005) study, 46% of synesthetes said that attention could increase the vividness of synesthesia with an equal number believing that attention had no influence. This aspect is shared with spontaneous and induced synesthesias. Induced synesthesias seem to be able to be manipulated by the person experiencing them to some extent. This aspect of the phenomenon is deserving of greater research. The role of automaticity and attention is one area of investigation that may distinguish idiopathic synesthesia from spontaneous synesthesias which by contrast appear to require some level of altered or absorbed states of consciousness to occur (Walsh, 2005).

Researchers have used different types of experiments to investigate the role of automaticity in idiopathic synesthesia. Tests of perceptual grouping (Ramachandran & Hubbard, 2001b) and tests of visual search (Blake, Palmeri, Marois, & Kim, 2005) have been used. In these experiments, synesthetes have been reported to show significant advantages over controls in the visual identification of graphemes. For example, Ramachandran & Hubbard (2001b) have shown that synesthetes could identify a geometric shape formed by letters that were hidden in a larger field of letters. Blake et al., (2005) investigated the synesthete W.O. in whom an oddball letter amongst a background of similarly shaped letters 'popped out' quickly. Upon further investigation of W.O. the researchers found that his search times were consistently faster than that for controls. However this type of finding is not reported consistently in the literature and others have shown that synesthetes do not have advantages in visual search tasks (Edquist, Rich, Brinkman, & Mattingley, 2006; Sagiv, Heer, & Robertson, 2006).

Researchers also use another experimental paradigm to test automaticity; the synesthetic version of the well known Stroop colour naming paradigm (Stroop, 1935). Users of such paradigms argue that interference in the synesthetic Stroop test indicates that synesthesia is automatic, and that the associations of graphemes to colour are involuntary and difficult to suppress (Mattingley, Rich, Yelland, & Bradshaw, 2001). Others argue that it indicates that synesthesia is genuine (Cytowic and Eagleman, 2009). A non-synesthete does not exhibit Stroop interference (Mattingley, Payne, & Rich, 2006; Smilek, Dixon, & Merikle, 2005).

- Spatially extended

Synesthesia is often reported to be projected outside the physical body in peri-personal space. It has also been reported as inside the head, behind the eyes or in the mind's eye. There is little doubt that for some synesthetes the experience is external. Australian sound and music to colour and shape synesthete Steve Glass demonstrates the nature of his projected synesthesia through an artistic work reproduced in Figure 5-4. Participant EL explains that her emotionally elicited colour and form synesthesias have a location in 3 dimensions. While she sees them "in her mind's eye" they are distinctly in front and have a location in space. Synesthetes usually report that there is a marked difference in their experience between this and imagined stimuli. Synesthesia is typified by strong individual differences between synesthetes. Researchers have hypothesised that there are distinct differences between people who experience their synesthesia as projected (projectors) or in their mind's eye (associators). Further, this difference may account for different results in some of the psychophysical experiments. Dixon, Smilek, & Merikle (2004) showed "that projectors and associators can be differentiated not only by their participative reports, but also by their performance on Stroop tasks". They found that projector synesthetes have more Stroop interference from their synesthetic associations when naming the screen colour than the interference they experience from the screen colours when naming their synesthetic concurrent colours. There are concerns that this distinction however, may not be useful because, according to Rich et al., (2006), synesthetes tend to change their use of these terms to describe their experiences over time.

- Memorable

Synesthetic experiences appear to improve memory and the experience itself is memorable. Participant SK declared; "I like calling our corporate council, his number is yellow, yellow, lime, yellow and the numbers go so well together. I have a good memory for numbers and peoples' names because of the colours which go with them". 71% of synesthetes surveyed by Rich et al., (2005) said that synesthesia was advantageous for remembering car registrations and telephone numbers. Some participants in their study used their synesthesia to organise files and many reported their synesthesia was pleasurable and a source of creativity. A smaller proportion of the sample reported their concurrent colours assisted in mathematics, particularly mental arithmetic, and in learning languages.

While several case studies have revealed the presence of synesthetes with superior memory capabilities (Bor, Billington, & Baron-Cohen, 2007; Yaro & Ward, 2007) a recent study suggests that case reports of significant and superior memory maybe due to several factors - including individual differences or selection bias (Rothen & Meier, 2009). Given the large number of case studies in the literature and the comparatively meagre number of group level analyses, their criticism seems justified.

Idiopathic synesthesia is not the only form of synesthesia which is memorable or has effects on memory capability. Induced synesthesias are vivid and memorable events. Meditation, which is a state in which synesthesia occurs, can also improve memory (Newberg, Wintering, Khalsa, Roggenkamp, & Waldman, 2010). The memorable aspects of idiopathic synesthesia seem to be linked to the specificity and consistency of the association between the inducing stimuli (the letter A resulting in the experience of the colour red). Simply put, it may be the association which is memorable and not the perceptual experience. As a diagnostic criterion for idiopathic synesthesia, memorability lacks precision. This makes it difficult to generate testable hypotheses about it. It is not surprising that we see so little work on memory and synesthesia.

- Loaded with affect

Synesthetic experiences appear to have an affective component (usually pleasant) and emotions can also be an inducing stimulus of synesthesia. When synesthetic correspondences are violated (e.g. when letters are printed in the wrong colour) synesthetes feel uncomfortable or distressed. In the case of two sound-colour synesthetes in our study, loud nightclubs with competing noise in the environment were visually overpowering and disturbing.

Some synesthesias occur with emotional qualities as the stimuli which induce the experience (Ward, 2004). Some occur with emotion as the result of synesthesia being induced from a sensory modality, such as touch (Ramachandran & Brang, 2008). Emotions can also be concurrent features with colour to letters or numbers. Participant EL reports that the number 3 can be "cheerful, silly and warm hearted". It is also yellow.

Not all synesthesias are an inherently emotional experience. Rich et al., (2005) study reported that only 19% of synesthetes have specific emotions as part of their synesthesia. These included feeling negatively toward people with names of unpleasant colours or irritation from road signs that appeared in the 'wrong' colour. 9% of these reported that synesthesia overloads their senses and is exhausting in certain situations, and 7% found it uncomfortable to be 'different' from other people.

In summary, much of the phenomenology of idiopathic synesthesia described against these criteria is shared with other synesthesias in the broad family. Consequently, idiopathic synesthesia cannot be easily distinguished using the descriptive terms available. Improvement to the taxonomy of synesthesia is needed. Balancing clinical observation and interview with experimental testing may be the best way to diagnose synesthesia.

1.2.5. Diagnostic Testing

The primary purpose of a diagnostic test for synesthesia is to distinguish between consistent idiopathic synesthetes and those who have either a good memory for associations between stimuli or good inter-sensory translation ability. Tests of genuineness (TOG) were established for such a purpose.

Two physiological methods and one behavioual method are proposed for testing for the genuine presence of synesthesia. The first physiological method is functional magnetic resonance imaging (fMRI) analysis and the second pupilometry. Although a wide range of fMRI studies have found differences in the structure and function of synesthetes' brains in areas such as V4 (Hubbard, 2005; Weiss, Zilles, & Fink, 2005), a great deal more work needs to be done before this method becomes a diagnostic tool. One issue that will thwart this effort is that synesthetes are a heterogeneous group and there are large individual differences between the brains of synesthetes (Hubbard et al., 2005). Paulsen & Laeng (2006) proposed the use of pupillometry for testing the genuineness of synesthesia. They found that grapheme-colour synesthetes experience statistically significant Stroop type interference and facilitation as measured by pupil dilation. This method is not simple to administer however, and may not be available to the majority of researchers wishing to examine issues in synesthesia. On that basis it may be currently impractical to test genuineness of synesthesia using Pupillometry. It does however, offer a novel approach and one which has great potential. The common use of these two physiological methods for testing genuineness are not currently practical and the behavioural method is preferred by researchers.

Early reports of synesthesia were usually case studies which described the correspondences between the inducing stimulus and its concurrent, e.g. Langfeld (1914). These case studies generally provided evidence of the durability of consistent associations over time. This durability and consistency is used as a behavioural diagnostic marker of the genuineness of synesthesia (Baron-Cohen et al., 1987) and retesting over time has become the standard paradigm for testing authenticity or genuineness of synesthesia. For the purposes of this thesis, we refer to this method as the 'retest consistency' paradigm. When assessing grapheme-colour synesthesia the test usually involves taking an audit of a participant's grapheme-colour associations and recording them for future reference. At some future date another audit is conducted after which the second set of matches are compared to the first. On most occasions synesthetes show very strong retest consistency. These tests can have very long interval periods between them. It is reported that controls perform poorly at this task – even after only a 2 week period or after training to create associative links (Asher et al., 2006). It is assumed that the strong consistency of reporting is an indicator of genuineness and consistency of synesthetic perception.

The method of administration differs across the TOG used by researchers. Some TOG collect written responses to written stimuli (Rich et al., 2005), others to auditory stimuli (Gray et al., 2006), some administer only letter stimuli and others include word sets. Early versions of the test did not use computers to administer stimuli or collect responses, but recent improvements to the method of administration have been made. Asher, et al., (2006) proposed an auditory and computer based automated version of the TOG. Here, the task was to match colours to the sounds presented and there was no visual presentation of stimuli. The sounds included 51 word and 48 non word sounds and responses were made by selecting from a paper based colour swatch set. The stimulus domain was automatic but the response domain was not. Therefore, in this testing method the responses of subjects are difficult to transfer to the computer for further psychophysical testing, reducing the potential utility of the test.

There are a number of concerns with the retest consistency paradigm TOG that have yet to be addressed. First, the tests only assess one aspect of synesthesia, the consistency of the association. The TOG does not assess the perceptual aspects of synesthesia. Further, there is no standardised reliability score across tests. That is to say, that there is no accepted level of performance required in the test that can be used to confirm synesthesia in an individual. It is impossible to tell whether the criteria used in one laboratory are the same as those used in another. The appropriateness of the test is also questionable as some synesthetes report that particular associations do change over time. Finally, in countries with small and widely distributed populations, such as in Australia and New Zealand, it may not be feasible to have synesthetes return to the lab for retesting over a long period of time.

A second paradigm has been recently introduced. This paradigm requires testing and retesting a participant without an intervening duration. We refer to this method as the internal consistency paradigm. Its use is increasing with the advent of large scale studies where participants are not available for retesting (Simner et al., 2006).

The first published use of a test of internal consistency was by Simner et al., (2006) to assess the prevalence of synesthesia among people attending a science museum. Simner et al., (2006) reports the consistency scores of participants against a set of known synesthetes on the basis of the total number of colour matches between the two iterations of grapheme presentation when the full set of 36 graphemes are presented. The Synesthesia Battery which also utilises the internal consistency paradigm has been recently released as a new set of tests that can be used to examine the genuineness of a wide range of colour synesthesias (Eagleman et al., 2007). It provides a standard set of tests and scoring to assess the genuineness of synesthesia. It calculates consistency in terms of the differences in the colour selections of graphemes of red, green, blue (RGB) channel values. The number of consistently coloured graphemes can also be calculated, making comparison with the retest consistency paradigm a simple matter. It is computer based, easy to administer, and is freely available both online and as a downloadable Matlab program. This is a significant improvement in the automated testing of consistency of synesthesia and also has the potential to assist in comparisons of data between researchers.

Like the retest consistency paradigm, this tests also uses a retest however, the main differences between this approach and others are:

- It is administered in one session and does not measure variability over time (although it can be used to do so).
- It uses the computer both to present the inducing stimuli and to collect the responses.
- It administers three examples of each stimulus randomly not two.

- It can confirm simply in one testing session, the non-synesthete status of control volunteers.

There are a number of other benefits in utilising this approach.

- It saves researchers time in retesting and the synesthetes the inconvenience of being retested.
- The durability of associations and internal consistency appear to be highly correlated so there may be no loss in accuracy of detection of synesthesia
- It can be reissued to a synesthete at a later date and can be modified to test subsets of graphemes or other inducers in subsequent sessions.

The weaknesses of testing internal consistency using computer based testing are:

- Durability over time is not measured, possibly increasing Type I error rates in studies.
- It takes about 45 minutes for a grapheme-colour test using 108 stimuli, and therefore appears to take longer than a similar paper and pencil test might.
- Despite having greater sensitivity to colour variability than other media (paper and pencil, coloured swatches or categories), synesthetes report that they sometimes cannot match computer colours to their synesthetic experience.

The Synesthesia Battery TOG are a technological improvement over previous approaches because they use a continuous colour palette rather than a subsample of colours or simple colour categories for response coding. This extends the utility of the test beyond simple assessment to the provision of standardised data which can be used to develop stimuli for other psychophysical tests.

One weakness all TOG share is that they do not have standardised diagnostic scores. Without proven scores for diagnosis, there are two clear risks which are relevant to researchers when using the TOG. These risks are best described as Type I and Type II errors; the false positive detection of a non-synesthete and the false rejection of a genuine synesthete, respectively. Typically researchers are careful to describe how they decide a particular case of idiopathic synesthesia is genuine and as such they have focused on eliminating what is considered to be the more serious of the two; Type I error. Dealing with Type I error is an important consideration in synesthesia research for the following reasons:

- Removing Type I error aids the comparison between synesthetes and controls by ensuring they are properly categorised.
- Synesthesia can be the result of injury, meditation or drug effects. These synesthesias may be quite different from the idiopathic variety and it is important to be able to distinguish between them.
- There is currently considerable positive influence of media reports about synesthesia. These reports discuss the advantages bestowed on those with synesthesia which can lead to people coming forward, hoping they might be synesthetes when in fact they are not.
- There was a very high level of scepticism in early reports of synesthesia which were dismissed as fanciful (noted by Cytowic (2002)).
- If the criterion for diagnosis is strict, researchers can be sure of having a distinct sample of synesthetes who have in common a very high level of consistency in the reporting of their synesthetic associations. Conversely, non-synesthetes are excluded from the sample and the potential noise present in the data is minimised.

However, the elimination of Type I error almost certainly forces some level of Type II error. The synesthesia literature gives the impression that idiopathic synesthesias are always strong, consistent, durable and well understood by those who experience them. However synesthetes report this is often not the case. Further, in the retest consistency paradigm although synesthete group scores indicate high levels of consistency in colour matching to graphemes, individual synesthetes are known to score below 100% match consistency. 50% consistency is the lower bound (Simner et al., 2006). It is possible that these imperfect scores could be the result of a lack of a synesthetic concurrent for some graphemes; some concurrent colours being too weak to be detected or some concurrent colours changing over time. In short, many synesthetes may score poorly on the tests for a range of different reasons and be falsely rejected. This creates a loss of participants who are experimentally and theoretically valuable because they provide important information about the variability and idiosyncratic nature of synesthesia.

Identifying those that are falsely rejected in study recruitment is also important because we are not yet certain whether synesthesia is a continuous or discrete phenomenon. For example, there is some debate as to whether one either has or does not have synesthesia, or whether one might have just a little (Ward, 2008). If synesthesia is discrete, a signal detection problem would be an easier task to resolve and a taxonomy of synesthesia might be a much simpler matter. If synesthesia is a continuous phenomenon, then it is possible that many more people enjoy synesthetic experiences than are currently estimated. It may even be the case that all individuals experience some limited automatic synesthesia (Maurer & Mondloch, 2005).

Finding the boundary between an authentic case of synesthesia and a false one is a genuine problem of signal detection. It is to this methodology that we turn to more strictly assess the utility and diagnostic power of the internal consistency method used in the TOG. We utilise the tests contained in the Synesthesia Battery for this purpose in Chapter 2.

If the Synesthesia Battery is a genuine improvement to existing paradigms then it should:

- be easy and efficient to administer,
- successfully complete the task, that is, distinguish between synesthete and control groups,
- confirm previous findings – at least not be at odds with them,
- provide new insights on old problems,
- open up new opportunities and research questions.

If the TOG are also found to be highly diagnostic, then we will know how certain we can be about whether an individual is suitable for inclusion into a synesthete group for study.

1.3. Explanations of Synesthesia

Synesthesia is a difficult condition from which to create a general theoretical account for a number of reasons. First, it is heterogeneous. Second, a specific and general taxonomy of synesthesia has not been established. Third, there is little work on other types of synesthesia than those elicited by graphemes and words. This makes the creation of a unified theory unlikely in the short term.

The first researchers to postulate a neurobiological explanation of the occurrence of synesthesia were Baron-Cohen, Harrison, Goldstein, & Wyke (1993) who asserted that synesthesia was a consequence of the breakdown of modularity in the brain. Since then several different explanations have been put forward. Theoretical accounts of synesthesia fall into four different classes: the localised cross wired hypothesis

(Ramachandran & Hubbard, 2001b; Ramachandran, Hubbard, & Butcher, 2002), the neonatal hypothesis (Maurer & Mondloch, 2005, 2006), the disinhibition hypothesis (Grossenbacher & Lovelace, 2001) and the associated learning hypothesis (Calkins, 1893).

- **The localised hardwiring hypotheses:** In this proposal, synesthesia reflects local cross-wired connections in the brain between inducer and concurrent processing areas such as in the Fusiform Gyrus between grapheme processing areas and V4 for grapheme-colour synesthesia (Hubbard & Ramachandran, 2005; Ramachandran & Hubbard, 2001b). There is neuroanatomical evidence that local or adjacent connections are more numerous in synesthetes than in non synesthetes (Rouw & Scholte, 2007) but there is some debate over whether this is a cause or consequence of synesthesia (Cohen Kadosh, Henik, & Walsh, 2009). The theory as it is currently put cannot explain synesthesias which involve more distant processing areas such as touch to colour or orgasm to colour synesthesia.

- **The neonatal hypothesis:** In this proposal, synesthesia reflects cross-wired connections between unimodal centres in the brain that are no longer present in the vast majority of adults. Maurer & Mondloch (2005) for example argue that all neonates are synesthetes and in adult synesthetes these connections have survived development. These could be local or long range cross modal connections. This could also include connectivity to the parietal cortex (Spector & Maurer, 2009).

Spector & Maurer (2009) suggest that infants have difficulty disambiguating multimodal stimuli into separate unimodal events. Synesthetes (who retain these infant synesthesias) therefore should also experience the same difficulty. We test this assertion in Chapter 7, by subjecting synesthetes and controls to the well known sound induced flash and fusion illusions (SIFFI) (Shams et al., 2000).

- **The Disinhibition Hypothesis** (Grossenbacher & Lovelace, 2001): In this proposal synesthesia is the result of disinhibition of the feedback or re-entrant pathways from bimodal or multimodal areas in the brain that are present in all people to some extent or another. Here, synesthesia either comes from connections between pathways or from feed-forward signals that activate feedback which is usually inhibited in non-synesthetes. The superior temporal sulcus (STS) was proposed to be a good candidate for a multimodal locus under this account because it sends feedback to uni-modal visual areas.

Given that synesthesia occurs under absorbed or focussed states of attention, and that these states are correlated with disinhibition, it would be interesting to know whether synesthetes report such states to a higher level than controls. Glicksohn, Steinbach, & Elimalach-Malmilyan (1999) have claimed that individuals who report high levels of absorption are good candidates for having synesthesia. This assertion has never been tested in a group of idiopathic synesthetes - only in groups of individuals with good cross sensory translation ability (Rader & Tellegen, 1981). In Chapter 6 we test whether idiopathic synesthetes are more likely to report a higher level of absorption in everyday activities.

There is also one explanation of synesthesia which emphasises the role of learning in development:

- **The associative learning hypothesis:** In this proposal, synesthesia is the result of over-learned associations. Marks & Odgaard (2005) cite Calkins (1893) and Claparede (1903) as proposing such explanations. Indeed even Marks own explanation for weak synesthesia is that it may be learned from association (Martino & Marks, 2001).

The associative learning hypothesis was first proposed by Calkins (1893). The hypothesis is nicely summed up by the following statement, taken from her paper.

> *"Colour with the letters may also be accounted for by arbitrary and forgotten childhood-associations; but it is possible that the explanation in this case is primarily a cerebral one. In general, however, such colour-associations are either useful or pleasant, so that, even if their occasion be cerebral, their continuance, both in the individual and in the family, is largely due to attention and to cultivation".*

However, since her seminal work very little effort has been put into progressing the theory. We discuss the reasons for this in Chapter 3.

Associative theories have several weaknesses, but most importantly they cannot explain why synesthetic associations survive in some people and not in others. There is also some difficulty in separating how learning in idiopathic synesthesia is different from the synesthesia defined by principled inter-sensory translation which is shared by all (i.e. lightness to pitch, pitch to size). From the evidence obtained to date, it appears that associative learning may not be an adequate explanation for synesthesia. However, learning does seem to play a strong role in idiopathic forms of synesthesia and any account of idiopathic synesthesia should consider the role it plays.

Theories of synesthesia simply do not adequately speak to its development (Marks & Odgaard, 2005). Theories should account for why synesthesia fails to develop in all people and whether spontaneous reports of synesthesia are influenced at all by any learning. If associative learning accounts are to be instructive in our understanding of synesthesia then they need to be brought into line with current theories of reading and letter recognition, or learning in development in general. We attempt to link the patterns of associations found in idiopathic grapheme to colour synesthesia to theories of letter identification and early reading in Chapter 3. Since there are 36 graphemes and 11 basic colour categories colour matching between them must occur. If this is systematic it might shed some light on how colours are applied to graphemes in development and give some indication of whether they are influenced in implicit or explicit ways. In Chapter 3 we also explore the colour associations of synesthetes to discern if there is any evidence for personally relevant grapheme-colour associations that might indicate high levels of exposure to grapheme and colour stimulus pairings suggestive of learned grapheme-colour associations.

1.4. Issues for Investigation

A number of challenges present themselves at the outset of any investigation of synesthesia. The most fundamental challenges is the ability to accurately identify that which is being examined. In synesthesia research these challenges manifest as; a lack of substantial phenomenological investigations across different synesthesia types, the use of imprecise terminology, and an ambiguous taxonomy. The difficulties involved in diagnosis motivated us to pursue a line of questioning about whether or not the TOG were diagnostic of idiopathic synesthetic individuals. We investigate this in Chapter 2. We also assess the utility of the TOG. This challenge is also manifest in the examination of poly-modal or multi-concurrent synesthesias, where a taxonomy or simple framework simply does not exist for their exploration. In Chapter 5 we examine in some detail two synesthetes who experience multiple concurrents in addition to colour. The presence of these cases does challenge, but not refute, the prevailing explanations of synesthesia and in particular the localised cross-wired hypothesis.

Two other types of challenges must be faced when investigating synesthesia. The first are the inherent methodological limitations due to the fact that synesthesia research is an emerging field. Emerging research fields are characterised by a lack of consensus, a need for organisation, cumulative inquiry and weak ties between researchers (Fagerberg & Verspagen, 2009). They appear to have similar features and challenges to emerging industries, which survive their infancy only when the collective participants agree to cooperate, create standards and build upon innovative breakthroughs (Ferrier, Trood, & Whittingham, 2003). Such an opportunity for the synesthesia research field is presented by the development and release of the Synesthesia Battery. The systematic sharing of data across countries and researchers that was envisaged by Eagleman et al., (2007) and made possible by a standardised testing regime, will be necessary to drive the field forward. Currently however, synesthesia research has little agreed taxonomy and the theoretical accounts of synesthesia are not simply incomplete, but are underdeveloped (the associative learning hypothesis, for example).

A second methodological issue relates to the widely used synesthetic Stroop paradigm. A great deal of the research upon which knowledge of synesthesia rests, is based on the paradigm, which might suffer from not using the best design manipulation. In the first instance, it is often not administered with a control condition. Secondly, synesthetes' grapheme-colour associations are administered to control participants, which does not control for whether control subjects may have colour associations to graphemes of their own. In all previously published TOGs researchers have only reported low levels of consistent colour associations for control groups. Not that there are none. In Chapter 4 we examine the nature of the synesthetic Stroop effect whilst improving the synesthetic Stroop experimental design.

The final challenge in synesthesia research is also an opportunity. Since the field is new and underdeveloped there is a great deal of opportunity for investigation and discovery. The two cases described in Chapter 5 develop our understanding of the complexity of the phenomenology of synesthesia but in this thesis we also take the opportunity to investigate three specific claims by direct experimental methods. First, in Chapter 3, we examine the claim by Day (2005) that synesthetes match colours to graphemes based on shape. Second, in Chapter 6, we examine the claim by Glicksohn, Steinbach, & Elimalach-Malmilyan (1999) that individuals who report high levels of absorption are good candidates for having synesthesia. Third, in Chapter 7 we test the claim by Spector & Maurer (2009) that synesthetes should experience the same difficulty as children disambiguating multimodal stimuli, by subjecting synesthetes and controls to the SIFFI (Shams et al., 2000).

1.5. Conclusion

There have been a number of calls in the literature for a better classification scheme for synesthesia (Rich et al., 2005). A great deal of work needs to be done on the taxonomy and phenomenology of synesthesia in order to understand the similarities and differences between phenomena both within and across the synesthesia family. This is important because we cannot as yet answer simple questions about the phenomena, such as whether they require similar or different types of attention and to what extent they share principles of translation from the inducing sense to the concurrent sense.

From a more pragmatic point of view it is also important that we can classify both within and across groups of synesthetes to ensure that the individual differences between synesthetes in these phenomena are not lost in research design or when we look at data across different studies. The study of idiopathic synesthesia can inform us about both the neural basis of perception as well as the neural basis of metaphorical and creative thinking and as such it is important to be capable of distinguishing between different synesthetic events, the predisposition of individuals to them and the manifestations of them in perceptual experience.

This thesis investigates several aspects of synesthesia from three foundations which drive innovation in most fields of inquiry. First, to advance the field, researchers must be able to better identify the states they are studying accurately and be able determine a classification scheme for them. With this in mind we initially examine the newest tools for classifying and diagnosing idiopathic synesthetes; the tests of internal consistency presented in the Synesthesia Battery (Eagleman et al., 2007). We further determine whether this tool is as sound as other methods by examining comparing its results with those reported in studies using traditional retest consistency paradigms. We provide improved diagnostic scores for the TOG we examined and comment on their sensitivity in Chapter 2. In Chapter 5, we specifically examine the shape concurrents seen in a variety of synesthesias and demonstrate that simple approaches for unpacking the phenomenology of varied types of synesthesias may be workable for large scale qualitative evaluations. More importantly these cases imply that current theories of synesthesia may need expansion and elaboration.

Second, to advance the field, methods must be improved and new technologies must be applied. Tests and taxonomies applied in the field are better tools if they are not at major odds with established facts and if they offer additional insights. In Chapter 3 we use the data from synesthetes and controls to uncover additional systematic principles used by synesthetes in associating colour to graphemes, principles that have not been systematically investigated before and which have a direct bearing on the associative or learning theories of synesthesia. We improve the basic methodological paradigm of the synesthetic Stroop test in Chapter 4 and demonstrate that the conclusions drawn in previous studies may need re-evaluation in light of a methodological shortcoming we rectify. In Chapter 4, we also verify a new type of synesthesia; geometric shapes to colour.

Finally, to advance any field of research, researchers must be able test both confirmatory or suggestive hypotheses. In Chapter 6, we test a speculative proposition, that synesthetes are more likely and more capable of engaging in absorbed states of attention than controls: a proposition which would support the disinhibition hypothesis. In Chapter 7, we examine the specific assertion that synesthetes would be more likely to have difficulty disambiguating a multimodal stimulus into its uni-modal constituents; a proposition which would support both the neonatal and cross wired hypothesis.

2. DIAGNOSING IDIOPATHIC SYNESTHESIA AND TESTING FOR ITS GENUINE PRESENCE

2.1. Introduction

A key issue in research on idiopathic synesthesia raised in Chapter 1 is how one objectively confirms that an individual is a synesthete. This is a particularly difficult issue because many characteristics of the clinical diagnostic criteria are shared by other members of the synesthesia family. One feature which stands out as being distinctive is that the concurrents that are experienced in idiopathic synesthesia are specific, consistent and durable over time.

Baron-Cohen et al., (1987) argued that for research to succeed it was necessary to take the diagnosis of synesthesia from a clinical and subjective setting to an experimental and objective one. This lead to the use of consistency of synesthesia as the basis of TOG. The consistency and/or durability of concurrents is only one aspect of the synesthetic experience, however, it provides an objective measure that can be used in the laboratory. TOG can be devised for nearly all the idiopathic synesthesia combinations listed by Day (2005), provided that the inducer – concurrent parings are, in fact, consistent. The vast majority of TOG used so far have colour as the concurrent being measured, but concurrents such as shape or texture could also be measured using computer-based testing.

TOG are commonly reported in the research literature however, there has been no evaluation of the utility or performance of the TOG themselves. A concern with the existing TOG relates to their diagnostic power. Diagnostic power is a function of how well a test separates synesthetes from controls both as a group and for individuals at a particular consistency score. There are two main paradigms used in the TOG. One tests colour match consistency over time (retest consistency) and one which retests within a single session (internal consistency). There is no set diagnostic score for the retest consistency paradigm and various researchers report different lower bound or minimum scores. In the case of the TOG used by Asher et al., (2006) for example, a score of 55% consistent colour matches to inducers from time 1 to time 2, was recommended as diagnostic. Using descriptive data they showed that there was no overlap between the group scores in the data at 55%. All synesthetes had colour match consistencies above 55% and non-synesthetes all fell below this score. They argued that if 55% consistency is used as the diagnostic cut off, misdiagnosis would be unlikely. In the first use of the internal consistency paradigm, Simner et al., (2006) present a range of known scores of synesthetes where the lower end of the range that synesthetes scored was colour matching of 18 of 36 graphemes. Like the Asher et al., (2006) study two data points were taken to determine consistency. In the published data, an overlap is shown between the control and synesthete samples with at least one control subject able to colour match up to 30 graphemes consistently. The methods used in these tests differ markedly so a direct comparison between them is difficult but two things are clear. First, the lower end of both paradigms demands that only approximately 50-55% of the graphemes be consistently colour matched for diagnosis of synesthesia to occur. Second, there is a discrepancy as to whether the TOG completely separates the test scores for groups of participants. This raises some doubt about whether TOG can accurately diagnose synesthesia at specific colour match consistency score, particularly near the boundary.

In this thesis, the utility and diagnosticity of TOG which use the internal consistency paradigm are evaluated. The tests published in the Synesthesia Battery[1] developed by Eagleman et al., (2007) are the medium through which this evaluation is undertaken. The core rationale for this assessment is that the internal consistency paradigm does not measure the durability of synesthetic association over time and may be considered or criticised as a weaker version of the test than the retest consistency paradigm. An overview of the Synesthesia Battery (Eagleman et al., 2007) was provided in Chapter 1. The key features of this Battery are that; a) it has a standard set of interview questions, tests and scoring, b) is computer based, c) is simple to administer and d) is freely available which makes it a highly attractive proposition for researchers by making their own development and construction of TOG unnecessary. The Synesthesia Battery is a significant improvement in the automated testing of synesthesia and has the potential drive comparisons of data between researchers as well as collecting large samples of data from around the world. The Synesthesia Battery is frequently updated and new tests which correspond to the different types of synesthesia are added regularly. At the time of use in the studies in this thesis, the tests included the TOG for graphemes, time units, sounds and a new paradigm, the speeded congruency test for graphemes was also included. The tests were available in two forms, an online version

[1] there are two versions of the synesthesia battery. All versions of the Colour Association Tests described in this thesis are based upon the downloadable MATLAB program provided by Eagleman (2007) at the Synesthesia Battery website which was obtained at http://www.synesthete.org in 2007. In this version, no standardised set of interview questions and no test for musical notes is available. In 2010 an updated version of the online battery is available which includes both of these features.

in which data is stored in the USA and a downloadable Matlab version which provided for independent researcher use. The downloaded version provided the basis of the TOG assessed in this thesis. The computer code in the downloaded version can be (and was) modified to include other inducing stimuli (such as emotional words etc) or response items (such as shape names) in addition to colour. Importantly, each test gives a colour match consistency score for each item, for each participant tested.

In the case of the Synesthesia Battery tests, Eagleman et al., (2007) recommended a maximum total colour match consistency score for diagnosis of grapheme to colour synesthesia which, like the tests described above, was based on the observation of descriptive statistics. The score is calculated as the total distance between the red, green, and blue (RGB) values of colour selections for each grapheme on three occasions. A low score indicates a high level of consistency in the RGB values for each selection. In the Eagleman (2007) study, the descriptive statistics published show that no overlap between synesthetes and controls scores was present, but only small groups of synesthetes and controls were examined. Further, no recommended colour match consistency score was given for other tests in the Synesthesia Battery.

The Synesthesia Battery has great promise and a high likelihood of future use. In addition to testing the utility of the internal consistency paradigm, there is pressing need to; independently replicate the findings of Eagleman et al., (2007); examine whether other TOG (i.e. music or time units) which use the internal consistency paradigm, can distinguish between groups of synesthetes and groups of controls; determine appropriate diagnostic scores for other tests in the Synesthesia Battery; and examine whether variability in the colour match consistency scores is systematic in any way that might relate to its method or design and finally extend the use of the test to the measurement of other concurrents (such as shape).

In this chapter, the TOG are evaluated in three ways. First, they are compared in terms of the result they give for the overall group differences between synesthetes and controls. Second, Signal Detection Analysis is used to test the overall power of the TOG as well as the sensitivity of particular scores produced by it. Finally, a comparison of the output between these internal consistency TOG and the retest consistency of the TOG of previously published work is undertaken.

2.1.1. Criteria for Assessment of the Synesthesia Battery and its TOG

In Chapter 1, several criteria were identified as needing to be met for a new research tool or method to be considered adequate or an improvement. First, the test or tool must be easy to use. Second, the tool must deliver informative results. Third, the tool must give results that are consistent with established facts or at least not be at odds with them and fourth, and most importantly, the use of the tool will open new lines of inquiry. It is against these criteria that we make our investigations.

2.1.2. Rationale for Using Signal Detection Theory (SDT)

The use of Signal Detection Theory (SDT) seems apt for the evaluation of the diagnostic ability of the TOG which use the internal consistency paradigm. SDT is a promising approach as it provides a "general framework to describe and study decisions that are made in uncertain or ambiguous situations" (Wickens, 2002). It has a track record in the diagnosis of certain medical conditions where, like synesthesia, self reports can be ambiguous or weak. SDT provides an opportunity to identify the most sensitive variability scores that discriminate between groups. It also enables the assessment of the effect of a range of colour match consistency scores in the tests on Type I and Type II error rates.

In short, SDT is a statistical methodology for determining the diagnostic power of the TOG and is superior to the use of t-tests between groups. It can assist in the evaluation of how well a test discriminates between groups and also in assessing whether a particular score is diagnostic of synesthesia in an individual.

2.1.3. Rationale for Comparison with Previously Published TOG Results and Investigation of Synesthetes' Reported Experiences of these TOG

The core rationale for this comparison is to defend the criticism that the internal consistency paradigm is a weaker version of the TOG than the retest consistency paradigm.

The association of colour to graphemes when assessed using the retest consistency paradigm is known to be somewhat systematic. (Rich et al., 2005; Simner et al., 2005). Synesthetes and controls also associate colours to graphemes in systematically similar ways. By comparing the results of the internal consistency TOG with reported retest consistency TOG it is possible to determine whether researchers can be confident that results of experiments which rely on diagnosis of synesthetes in one paradigm can be generalised to others. If there is a strong relationship between the output of the different TOG paradigms, ease of interpretation and generalisation of future research outcomes is enhanced.

Synesthetes disclose that some grapheme colours change over time, but this is rarely reported in the literature. It has largely been ignored for study with researchers - preferring to focus on how grapheme-colour synesthesia is consistent, specific and reliable. The causes underlying variability in the reporting of colour associations by synesthetes is an intriguing issue and worthy of further investigation. To understand this, one must examine synesthetes reported experiences of the test. As such we examine the data for systematic influences and sources of variability described by synesthetes in a debrief interview.

2.2. Design

2.2.1. Experiments

The following series of TOG using the internal consistency paradigm were administered. The aims and hypothesis tested in each experiment differ slightly and are reported in the next section. Each TOG is reported as a separate experiment:

- **Experiment 1 –Grapheme induced colour synesthesia**
  - **a - Graphemes** – Grapheme Colour Association Test (GCAT) – This test asks participants to match colours to graphemes. It produces colour match consistency scores for the numbers 0-9 and letters A-Z and a total colour match consistency score.
  - **b - Speeded Congruency** – Speeded Congruency Test (SCT) - This test produces a percentage accuracy score of participants' responses to whether a grapheme was presented in either a congruent or an incongruent colour to that which was chosen by them in the GCAT.

- **Experiment 2 –Time Unit induced colour synesthesia**
  - **Time units** - Time Unit Colour Association Test (TUCAT) – This test asks participants to match colours to time units. It produces colour match

consistency scores for months and weekdays and a total colour match consistency score. It is a combination of the weekday and months Synesthesia Battery test.

- **Experiment 3 and 4 – Auditory induced colour and shape synesthesias**
  - **Musical notes** - Music Colour and Shape Association Test (MCSAT). This test asks participants to match a) colours and b) shapes to single musical notes. It produces colour match consistency scores for each of 44 musical notes and 5 noise bursts presented, and a total colour match consistency score. It is a modified version of the sounds Synesthesia Battery test for which we have substituted musical notes. It is directly comparable to the current online Synesthesia Battery test of musical notes except that a second task is undertaken in this test. That task is to match shapes to musical notes. A total shape consistency score is computed.
  - **Sounds** – Sound Colour and Shape Association Test (SCSAT). This test asks participants to match a) colours and b) shapes to sounds. It produces colour match consistency scores for each of 47 different sounds from the environment, including nature, animal, human and machinery sounds and a total colour match consistency score. It is a modified version of the sounds test in the Synesthesia Battery to which other environmental sounds have been added. It is directly comparable to the current test for sounds except that a second task is undertaken in this test. That task is to match shape names to sounds. A total shape consistency score is computed.

2.2.2. General Participant Information Across Experiments 1 to 4

2.2.2.1. Recruitment and Ethics

A variety of sources were utilised to recruit participants, including advertising on the internet, advertising through the first year psychology participant pool, and word of mouth. Given the varied nature of our recruitment procedures and the limitations of participants time, not all participants contributed to all of the TOG experiments. Several participants volunteered their time but in the main participants were reimbursed $20 per hour of testing or received course credit for the time involved. All participants gave informed consent and the study was approved by the Human Research Ethics Committee of the University of Sydney.

2.2.2.2. Self Referred Synesthetes

Thirty self referred synesthetes were recruited and participated in the various TOG in the three year period between 2007 and 2009. The ages of the synesthetes ranged from 19 years through 49 years with a mean age of 25.2 (N = 30, S.D. = 8.94). Many of the synesthetes indicated they were poly-modal, having a variety of other forms of synesthesia, such as time unit to colour, music to colour, smell to colour, touch to colour, orgasm to colour and spatial sequence synesthesia. 83% had some form of musical training in childhood with 25% currently engaged in music as either a professional or semi-professional pursuit.

2.2.2.3. First Year Students

One hundred and thirty participants were recruited from the first year psychology participant pool in the three year period between 2007 and 2009 for the range of TOG conducted[2]. The ages of the first year participants ranged from 18 to 46 with a mean age of 20.12 years. (N = 106, S.D. = 3.43). 93% of first year participants reported that they had received some musical training in childhood.

2.2.3. Procedure

The following general procedure was common to all TOG experiments.

- All participants completed a synesthesia experiences checklist (SEC). This is a simple checklist of different types of synesthesia in which participants are asked if they ever experienced a particular type. This was coded Yes or No and appears in Appendix B[3].
- A selection of the TOG were administered.
- All participants were interviewed and debriefed about their scores on the tests and the nature of synesthesia.

The debrief interview procedure helped ensure that synesthetes and false positives (such as pseudo-synesthetes) were identified in the first year student participant

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[2] Other tests from the Synesthesia Battery were conducted during this period but are not reported in this thesis.

[3] All participants were also administered the Modified Tellegen Absorption Questionnaire (Jamieson, 2005). This appears as Appendix A and is reported in Chapter 6.

sample. The debrief consisted of a discussion of the scores obtained. A debrief sheet explaining synesthesia, particularly grapheme-colour and music-colour forms, including references was discussed and given to each participant. All participants were asked if they thought they may have some forms of synesthesia. They were further asked to re-contact the researchers if at a later date they thought they may have any other forms of synesthesia after now having been provided more detailed information on aspects of synesthesia.

For self referred synesthetes, a more descriptive interview was conducted. They were asked whether their experiences were voluntary, whether they were projected or internal, and whether they were enduring over time. Where time permitted, an audit of other synesthesias was also conducted and a personal history taken.

2.3. Grapheme Induced Colour Synesthesia

2.3.1. Experiment 1a – Grapheme Colour Association Test (GCAT)

2.3.1.1. Aims and Hypotheses

The specific aims of this experiment are to:

- Verify the previously published results of this TOG (Eagleman et al., 2007).
- Examine the diagnostic power of the test through the use of SDT.
- Derive the best colour match consistency score for the test that considers Type I and Type II errors.
- Compare and contrast the results of the internal consistency paradigm with the published results of the TOG retest consistency paradigm used by Rich et al., (2005) and Simner et al., (2005).
- Evaluate the variation in the test scores due to different phenomenological aspects of synesthesia.

The working premise is that the internal consistency paradigm can accurately diagnose synesthesia at the recommended diagnostic score. If the internal consistency paradigm is at least as useful as the retest consistency paradigm, then the following results will manifest:

- The test will distinguish between synesthetes and controls at the group level using a t-test, as the retest consistency paradigm does.

- The TOG will be highly sensitive at particular colour match consistency scores. Sensitivity, measured by *d'* in the SDT will be large, suggesting good separation between the synesthetes and controls scores.
- The test will give similar qualitative results to (or at least not be at odds with) previous published studies using the retest consistency paradigm (Rich et al., 2005; Simner et al., 2005).

2.3.1.2. Method

The Grapheme Colour Association Test (GCAT) measures the consistency of RGB channel values for colours chosen on each of the three occasions that the numbers 0-9 and letters A-Z are presented.

2.3.1.2.1. Participants

One hundred and fourteen naive first year students and thirty self referred synesthetes participated in the test of the GCAT. Twenty-six self referred synesthetes reported colours for graphemes. One synesthete reported projected synesthesia for graphemes.

2.3.1.2.2. Stimuli Presentation

Stimuli were designed and presented using Matlab on either a Sony Trinitron G520 monitor or a Sony Multiscan E220. Graphemes were presented in Helvetica (font size 50). The subtended approximately 2.5 degrees of visual angle. Participants were seated one metre from the screen. Responses were recorded automatically by the computer program. Stimuli remained onscreen until a response was recorded.

2.3.1.2.3. Instructions

All thirty six graphemes (A-Z, 0-9) were presented in random order three times making a total of one hundred and eight stimulus presentations. Participants were instructed to choose the colour that best matched the letter or number presented on the screen. If participants requested further information about colour selection they were then instructed to choose colours by whatever method they thought appropriate. A set of test trials was given (three letters) and these data were discarded.

A single grapheme was presented along with a colour palette (Figure 2-1). Colour selections were made by positioning a set of cross hairs over the colour palette and pressing the left mouse button to select the colour. A final choice was registered by pressing the keyboard space bar. Participants were instructed that they could make colour choices lighter (to white) or darker (to black) by pressing the keyboard arrow keys left or right respectively.

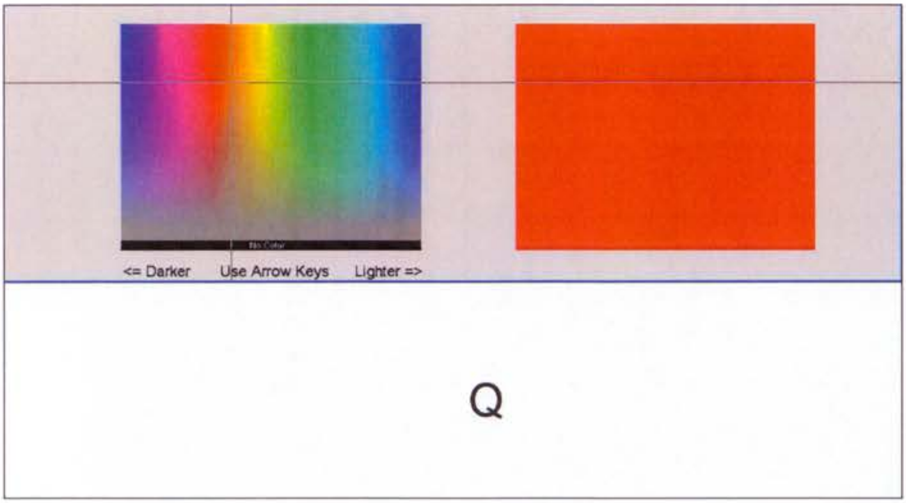

Figure 2-1. Screen display of GCAT stimulus selection

2.3.1.2.4. GCAT Data Collection and Analysis

Three values for each grapheme were collected corresponding to the RGB colour channels on the computer for each of the one hundred and eight presentations.

A colour match consistency score for each grapheme was determined according to the formula in Eagleman et al., (2007) which represents the total difference between each selection in RGB terms. According to Eagleman et al., (2007) the color variation for each letter (*vj*) is measured by:

$$v_j = \sum_{c=\{R,G,B\}} |x_1^C - x_2^C| + |x_2^C - x_3^C| + |x_3^C - x_1^C|$$

This represents the geometric distance in RGB color space. Values are normalized to lie between 0 and 1. The total score for a participant is:

$$V = \frac{\sum_{j=\{A-Z,0-9\}} v_j}{N}$$

where N is the total number of graphemes for which the participant experiences synesthetic colours.

A low colour match consistency score indicates a close proximity between the RGB values and therefore high level of correspondence between the colours selected on each occasion. A high colour match consistency score indicated a distant proximity between the RGB values and therefore a low level of correspondence between colours selected on each occasion.

A total colour match consistency score was also computed for each participant. The total colour match consistency score discards from the total any letters for which a colour was not chosen and takes an average of the remainder. Thus this total score was computed only for those graphemes for which a colour was selected on all three occasions. A total colour match consistency score with a value "under 1" is recommended by Eagleman et al., (2007) to diagnose synesthesia.

For each data analysis, Levene's statistic was checked and if found to be significant an adjusted t value is reported.

2.3.1.2.5. Method of Data Analysis for Comparison with Previously Published Retest Consistency Data

In order to make the RGB data comparable to the Rich et al., (2005) study, the RGB values of the colour selections made by participants were converted into the eleven basic colour categories (Berlin & Kay, 1969). A Matlab program was designed to play back the colour selections of GCAT participants. Figure 2-2 below shows the stimuli created to undertake the task. The program was designed to first automatically assign the labels black, white, grey and 'no colour' - as they have RGB values that are simple to extract – and to present all other values for assessment by an observer. For the remaining graphemes we asked three judges (two independent to the study and the author) to view the presented colour and assign it to one of the 11 basic colour categories. This data point was presented as a colour patch with a simultaneously presented dialogue box listing colour category names. For each item, the judge made a choice from the category names which best represented the colour presented from the dialogue box. This was recorded for each grapheme. Only the first row of data in the GCAT (which corresponds to the first colour selection for a grapheme) was used in the subsequent analysis.

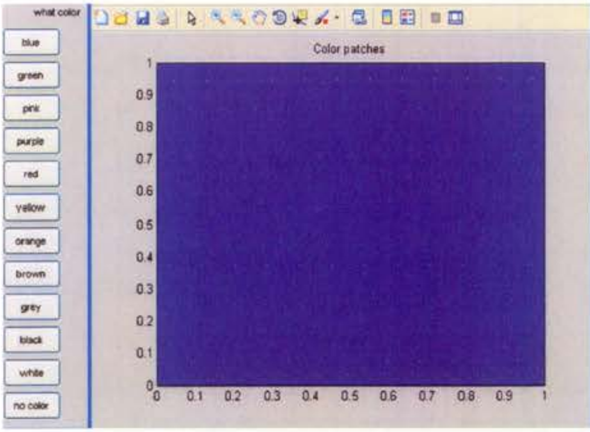

Figure 2-2. Screen display of colour categorisation task made by judges

The next step compared the results of the two judges. Both judges were independent to the research and naive to the purpose of their task. Where there were differences, the process for selecting which colour was decided by whether the third judge (the author) had recorded a response which agreed with either the first or second judge. If all three judges failed to agree, the third judge examined all three selections along with the colour palette and decided on the colour. This was rare - 15 occasions from a total of 4896 trials.

Some points of note affecting colour categorisation need to be stated. It can be difficult to category code some items when they fall on the boundary between category colours. Judges may not have assigned the same colour label as the participant would have themselves. Judges were instructed to select for hue rather than achromatic when pressed for a choice. For example, some synesthete participants have very light and pale shades of blue or yellow for zero or for the letter O. Judges were instructed to classify these types of colours as the shade of colour detected rather than white though it is arguable that these may be more white than blue for example. Synesthetes on occasion describe their selections as bluish white or white when asked to assign a colour name to them but when using the computer program have been as precise to their internal representation as possible. Likewise, very dark hues of blue and purple are coded as such rather than black.

The data analysis procedure described in Rich et al., (2005) is replicated to determine whether a colour is significantly associated to a particular grapheme. In that study a significant association is defined as graphemes which are chosen by the group more often than 2 SD over the mean number of associations for that colour. This was applied to each grapheme in the set for each colour. For example, in our sample, the colour orange is chosen by controls 3.6% (SD = 0.003) of the time across the total sample and 9.5% (SD = 0.006) by synesthetes. A significant trend would be considered for any letter having a frequency of being chosen by more than 10% (3.6% plus 2 SD) for controls and 21% (9.5% plus 2 SD) for synesthetes. Those graphemes falling within 1% of that value are also reported. Where the data differs from the Rich et al., (2005) study, we also state whether the colour match for a grapheme was one of the top 5 most popular matches for that colour for the group and vice versa.

2.3.1.3. Results

2.3.1.3.1. Self-Referred Synesthetes

Twenty-two of twenty-six grapheme-colour synesthetes scored below the recommended cut off score of 1. One of the participants reported having an incomplete grapheme-colour set at interview and was also found to have failed to record colour selections for over one third of the stimuli. This participants data were removed from further analysis.

Four of twenty-six grapheme-colour synesthete participants (15.4%) scored over the recommended cut off of 1. Three of these scored only marginally higher (i.e. within 10% of the recommended cut off score). The values were 1.06, 1.07 and 1.12 respectively. The other participant scored 1.49. Visual examination of this participants grapheme-colour selections revealed that many of the graphemes were consistently colour matched (20 of 36), but this was not the case for the full grapheme set. In several cases the variability score of some graphemes was extremely high and this drove up the average score. Unfortunately, this participant was unavailable for retesting. We do not exclude this datum because attempts were made for all graphemes and because it is also higher than the lower bound of 18 of 36 graphemes reported by Simner et al., (2006).

The four synesthetes who did not report grapheme to colour synesthesia scored over the recommended cut off of 1 as expected. One of these participants was also found to have failed to record colour selections for over one third of the stimuli. This participants data were removed from further analysis.

In summary, twenty-one of twenty-six (81%) grapheme-colour synesthetes scored in the recommended diagnostic range (under 1.0) and were correctly identified by the test. Four of twenty six (15%) were missed for diagnosis and one synesthetes data set was excluded.

2.3.1.3.2. First Year Psychology Student Participants

34.3% of first year participant pool participants responded 'Yes' to the SEC questions on colour associations for letters and numbers. This may indicate the awareness of the presence of some possible semantic (albeit not perceptual) associations. More importantly, this large number highlights the fact that a simple questionnaire such as the SEC has little usefulness as a screening tool for idiopathic synesthesia.

From the group of one hundred and fourteen first year participant pool participants, six participants failed to complete colour selections for at least one quarter of the stimuli or did not complete the SEC. Their data were removed from further analysis.

From the remaining participants, nine (8.3%) scored below the recommended colour match consistency score of 1. The nine participants results are described as follows:

- Two participants were confirmed to be synesthetes. They reported having grapheme to colour synesthesia, coloured hearing and other types of synesthesia. Grapheme-colour synesthesia was confirmed through retesting and re-interview at a later date.

- Three participants responded 'No' to the SEC questions both on coloured letters and numbers and said they had no synesthesia in the debrief interview. They did not report the use of any special approach to completing the test but upon visual inspection of the data it appears that a strategy of selecting colours for graphemes in blocks is apparent (for example the numbers 2,3,4,5,6 are all the same shade of blue). This would give a lower GCAT score than if different colours were selected, and therefore lead to a false diagnostic test score.

- Four participants responded 'Yes' to either the SEC question on coloured letters or coloured numbers but none reported synesthesia in the debrief interview. Three were available for further testing on the day and/or on subsequent days.

    - One of the three participants retook the full GCAT test after a period of eleven months. The score remained in the same range (first GCAT score =

0.82, second = 0.89). However, only 9 of 36 (25%) graphemes were the same colour in both sets. Figure 2-3 and Figure 2-4 show the colour selection choices of this participant on the first attempt and on the second respectively. This is indicative of a lack of idiopathic synesthesia.

Figure 2-3. Screen display of GCAT data for participant RB. Bar height indicates level of consistency. Tall bars indicate poor consistency. First testing session.

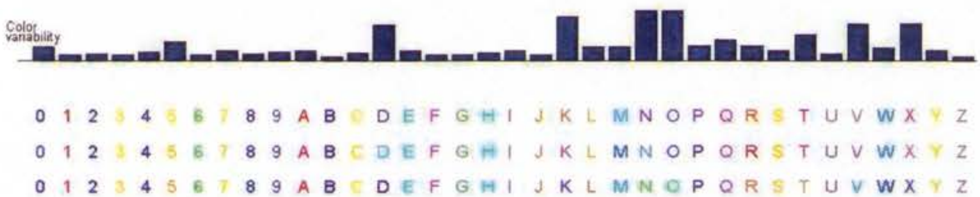

Figure 2-4. Screen display of GCAT data for participant RB. Bar height indicates level of consistency. Tall bars indicate poor consistency. Second testing session.

- Two of the three participants undertook the speeded congruency test, which was conducted on the same day as the GCAT. The speeded congruency test is a new tool available in the Synesthesia Battery and is designed to be used in conjunction with the GCAT. We report on the results of this test in the following section but include these participants results here for illustration.

  - one participant scored less than 70%. This according to (Eagleman et al., 2007) is indicative of a lack of synesthesia, and;

  - one participant completed the speeded congruency test on two occasions. One was conducted on the same day as the GCAT and the other was conducted after 6 months. The accuracy scores were 97% and 45% respectively. The former score taken together with the GCAT score would - on the day of testing - indicate synesthesia. The latter score would indicate a lack of synesthesia as the associations were not durable.

In summary, only two of the nine (22%) first year psychology student pool participants who scored in the diagnostic range for synesthesia reported that they were synesthetes at interview. The remaining seven achieved diagnostic scores through a variety of means, including applying the same colours to a sequential block of numbers or letters.

The remaining ninety-nine first year psychology student pool participants scored over the recommended cut off score of 1. Ninety seven were confirmed at debrief interview not to have grapheme-colour synesthesia and two were discovered as synesthetes. We report the process of our confirmation of their synesthesia as follows:

- One was confirmed to have grapheme to colour synesthesia through interview, retesting and re-interview. The initial GCAT score was 1.10 and 0.67 at retest after 13 months with the same colour selections.

- One reported mainly gendered graphemes and no colour synesthesia for letters. However, most of the numbers also had consistent colours. The total GCAT score was 1.72 or 1.05 when assessed using numbers only. Gendered graphemes were verified as consistent 12 months later. We use the value of 1.05 for future analysis.

In summary, at the recommended diagnostic colour match consistency score, 90% of first year psychology student pool participants were correctly rejected but 6% were falsely identified as synesthetes. 2% of first year psychology student pool participants were correctly identified as synesthetes and 2% were missed as synesthetes, i.e. only 50% of the genuine synesthetes in the first year psychology student pool participants sample were diagnosed at the recommended cut off score.

2.3.1.3.3. Group Differences

For the analysis of GCAT data, and from this point forward in the thesis, we will refer to the groups as synesthetes and controls. The four discovered synesthetes from the first year psychology student pool were appropriately included in the synesthete group. After the excluded data were considered, twenty-nine grapheme to colour synesthetes comprised the synesthete sample. The three completed tests from the non grapheme-colour synesthetes have been included in the control group giving a total control sample size of one hundred and seven.

We report group differences using two measures. These are the average colour match consistency score and the proportion of consistent graphemes in the set. The former measure is used by the internal consistency paradigm and the latter is a measure used by the published retest consistency paradigm TOG. We define each grapheme as consistent if its total colour match consistency score is less than 1.

Figure 2-5 shows that synesthetes (N = 29, M = 0.78, S.E. = 0.06) have more consistent colour selections for graphemes than controls (N = 107, M = 2.09, S.E. = 0.07). $t(95.13) = 14.61$, $p < 0.001$.

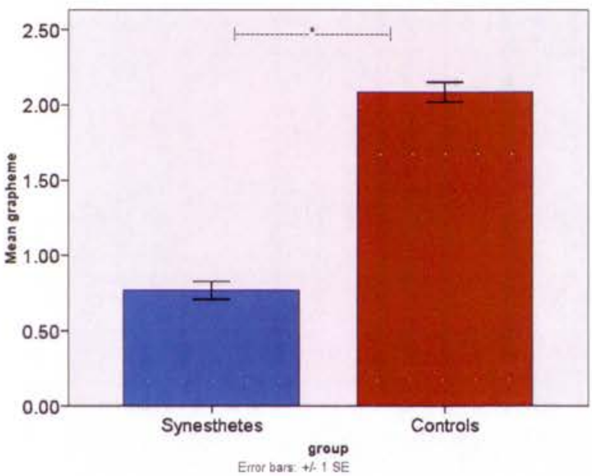

Figure 2-5. GCAT Mean and S.E. of colour match consistency scores for synesthetes and controls. * indicates t test between groups reaches significance

Figure 2-6 shows that the average proportion of consistently coloured graphemes[4] in the data set provided by the synesthetes (N = 28, M = 0.844, S.E. = 0.03) (84.4%) is higher than that for controls (N = 107, M = 0.301, S.E. = 0.02) (30.1%). $t(62.36) = 16.25$, $p < 0.001$.

[4] Note: we do not include in the data, any of the selections for 'No Colour' because other studies do not use it and it would reduce the direct comparison.

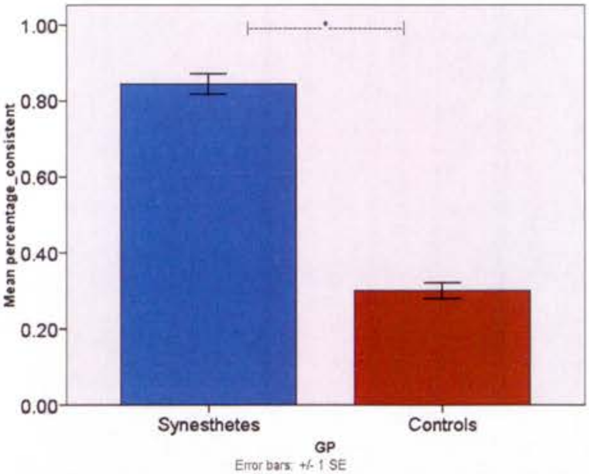

Figure 2-6. Mean and S.E. for proportion of consistent graphemes for synesthetes and controls. * indicates t test between groups reaches significance

This level of consistency is comparable to the figures reported in Rich et al., (2005); synesthetes 87% and controls 26%, and slightly lower than those reported in Simner et al., (2005) – synesthetes 93% and controls 36%, or Simner et al., (2006) – synesthetes 86.5% and controls 36.9%. Both studies cited collected two data points utilising a retest consistency paradigm.

2.3.1.3.4. GCAT SDT Analysis

d' values for the range of scores in the GCAT were derived to assess how well the scores discriminate between synesthetes and controls at particular colour match consistency values. For the purpose of the SDT the finalised results of GCAT testing and interview were combined into a SDT table of Hits, Misses, False Alarms and Correct Rejections for each 0.1 increase in GCAT score between 0.5 (good consistency) to the score of 2 (poor consistency).

The following is a guide to the classification:

- Hits: Grapheme to colour synesthetes with a score less than the GCAT value being assessed
- Misses: Grapheme to colour synesthetes with a score greater than the GCAT value being assessed
- False Alarms: Controls with a score less the value than the GCAT value being assessed

- ➢ Correct Rejections: Controls with a score greater than the GCAT value being assessed

This classification approach was applied to the SDT analysis for all the TOG evaluated in this chapter.

Figure 2-7 presents *d′* values for the GCAT test scores between 0.5 and 2.0. There are three peaks of sensitivity. The first appears at the GCAT score of 0.7, which corresponds to the point where no false alarms are present - all possible Type I errors have been accounted for. The next peak on the graph is at 1.2[5]. This represents the score which best divides the groups without fully accounting for either Type I or Type II error to the exclusion of the other. In this case, 28 of 29 synesthetes are correctly identified as hits. Notably this is slightly higher than the recommended cut off point of 1.0. The third peak appears at 1.5, which corresponds to the GCAT score where the highest *d′* value occurs and where the last synesthete has been recorded as a hit. Here, all possible Type II errors have been accounted for and interestingly, this occurs after a decline in sensitivity suggesting that 1.2 might be the more appropriate diagnostic score for general use. Researchers wishing to apply a strict criteria in their studies to ensure no false alarms should use the 0.7 value. Overall diagnosticity as measured by subjective signal strength (*d′*) of this test is high.

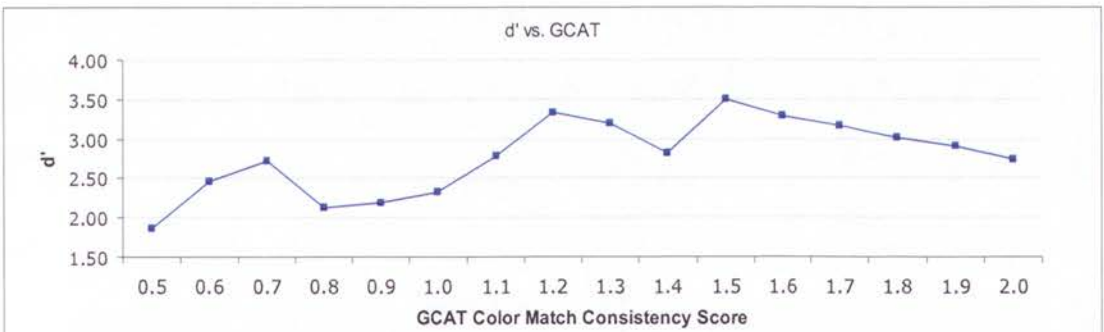

Figure 2-7. *d′* vs. GCAT colour match consistency score

[5] Since we derive the values in increments of 0.1 this is the diagnostic score. If we had derived our values as smaller increments, the actual value would be 1.12.

2.3.1.3.5. Colour Allocation to Graphemes: A Comparison with Rich et al., (2005)

Data is presented for each of the 11 basic colour categories used by Rich et al., (2005) as well as one category unique to the GCAT: 'no colour'.

For clarity, there are two minor differences between our studies. First the Rich et al., (2005) study did not assess the number zero which is included in the GCAT. Secondly, the GCAT includes 'no colour' as a selection response on the palette. This was not mentioned in the Rich et al., (2005) study. Further there are no reports of 'no colour' being used as a category of colour allocation in any other previous studies of grapheme to colour selections in synesthesia despite synesthetes reporting weak or transparent associations for graphemes. In this study therefore the responses are distributed over 12 categories rather than the 11 basic categories, making comparison between the studies in absolute 'percentage of times chosen' unhelpful. The results for each colour category are presented separately.

No Colour/Transparent

Across the entire grapheme set 'no colour' was chosen by controls 2.0% and by synesthetes 3.8%. Figure 2-8 shows the frequency distribution for all letters. Synesthetes sometimes reported that graphemes may not have coloured concurrents, or that these were transparent. They reported that they selected 'no colour' for graphemes which were either very pale, translucent or transparent. They stated that if they were forced to make a choice of colour name they would have selected white or black. We could not find any references in the literature to the use or incidence of uncoloured graphemes by synesthetes. This would be an interesting issue for examination, particularly as our data showed some graphemes have a high likelihood of being uncoloured. It is also possible that this provides a confound in the data analysis. The 'no colour' choice often does not represent a lack of an association for that grapheme by the synesthete but rather one that is difficult to represent using computer based tests. A 'no colour' choice might still represent a specific association but one which is difficult to describe.

It is not evident from previous synesthesia research using paper and pencil tests which graphemes would be less likely to be coloured and whether synesthetes would report letters with 'no colour' at a higher rate than controls. Here, synesthetes do not make more 'no colour' choices (N = 28, Mean = 1.36, S.E. = 0.31) than controls (N = 107, Mean = 0.96, S.E. = 0.156). $t(133) = 1.176$, $p = 0.242$.

It can be seen from Figure 2-8, that both synesthetes and controls have significant 'no colour' selections for zero. Synesthetes also have a significant association of 'no colour' for the letter O. There are three ways this information may be processed by synesthetes. There is a shape similarity for the number 0 and the letter O. A phonetic similarity exists between the word zero and the pronunciation of O and there is a contextual reason that zero indicates a lack of number, which may equate to it having a lack of colour.

Interestingly a 'no colour' choice also seems popular (though not significantly so) for letters at the end of the alphabet.

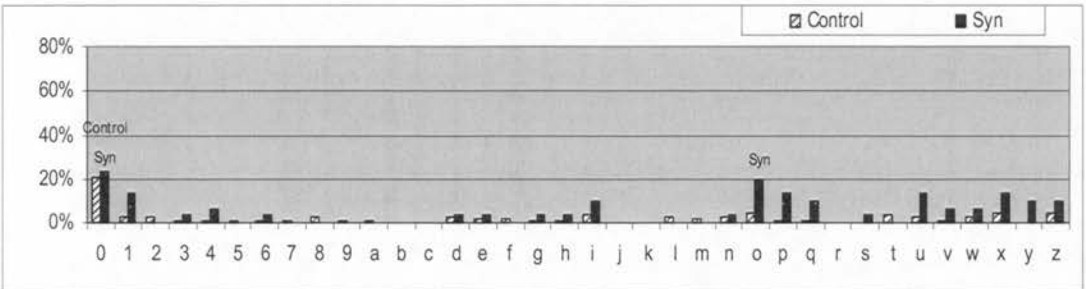

Figure 2-8. The frequency distributions of 'No Colour' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour

Black

Across the entire grapheme set 'Black' was chosen by controls 2.4% and by synesthetes 3.8%. Figure 2-9 shows the frequency distributions for all letters.

Like Rich et al., (2005), that we found significant associations for black with the letters X and Z for both groups. An additional significant association for synesthetes with black and the letter O and the number zero was found. Again we note the shape similarity for 0 and O. We did not find a significant association for the number one to be black as in the Rich et al., (2005) study although it is in the top 5 most popular choices for black by synesthetes. The comparison is listed in Table 2-1.

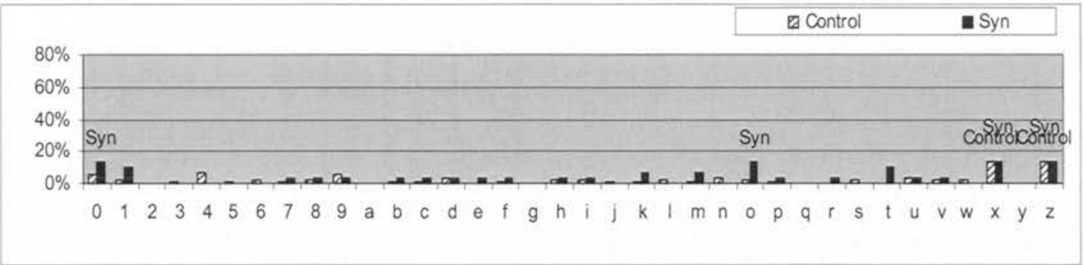

Figure 2-9. The frequency distributions of 'Black' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour

Black	Rich et al., (2005) Synesthetes	Synesthetes	Rich et al., (2005) Controls	Controls
O	Top 5	Significant		
X	Significant	Significant	Significant	Significant
Z	Significant	Significant	Significant	Significant
1	Significant	Top 5		
0	Not assessed	Significant		

Table 2-1. Comparison of significantly associated graphemes for 'Black' for both synesthetes and controls. Compared to the Rich et al., (2005) data.

White

Across the entire grapheme set 'White' was chosen by controls 0.5% and by synesthetes 2.7%. Figure 2-10 shows the frequency distributions for all letters.

Table 2-2 shows that there are differences between our results and those of the Rich et al., (2005) study. For example, our control participants did not show any association for white with the letter I or W. We saw trends for the use of white with the letters A and E in our sample. This was not evident in the Rich et al., (2005) study. This difference is likely due to the type of test used, particularly for the letter W as Rich et al., (2005) makes use of categorical colours, written by participants. Colour name matching to the first letter of the colour name could be primed by seeing the colour name written or by having to write it on a response sheet. White is not an obvious colour on the GCAT palette. An effort has to be made to select white on the colour palette, making its use in this way less likely.

White was significantly associated with the letters I, O for synesthetes and for the number 1 which replicated the Rich et al., (2005) study. A strong association for white with O was also noted by Calkins (1893), Baron-Cohen et al., (1993) and Day (1996). However for synesthetes in our sample we also found a significant association for the letter Q. This was a top 5 popular choice in the Rich et al., (2005) study. Additionally we find significant associations for both groups for the number zero.

Even though the pairing of the letter O with white reaches significance, it is used at a much lower level than in the Rich et al., (2005) study (less than 20% here and greater than 50% in the Rich et al., (2005) sample). The lesser overall percentage chosen value of O as white for synesthetes may be attributed to the additional and large response of 'no colour' choice by participants in our study. The comparison is listed in Table 2-2.

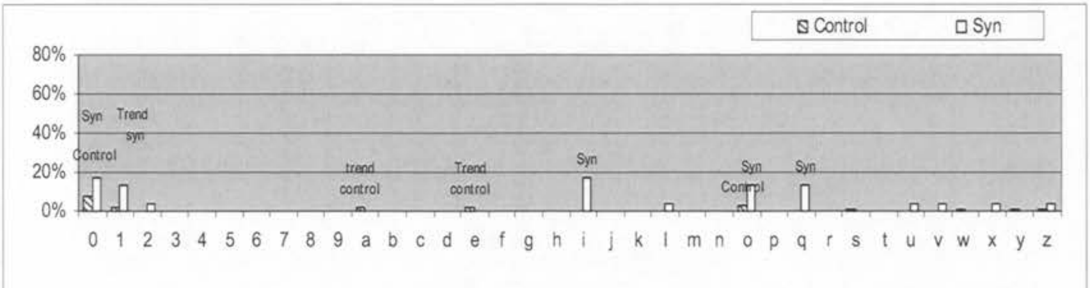

Figure 2-10. The frequency distributions of 'White' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour

White	Rich et al., (2005) Synesthetes	Synesthetes	Rich et al., (2005) Controls	Controls
0	Not assessed	Significant	Not assessed	Significant
1	Significant	Significant	Significant	Trend
I	Significant	Significant	Significant	*
O	Significant	Significant	Significant	Significant
Q Top 5	Significant	Significant	Significant	*
A			*	A trend
E			*	E trend

Table 2-2. Comparison of significantly associated graphemes for 'White' for both synesthetes and controls. Compared to the Rich et al., (2005) data
* denotes that the result is not consistent between the studies.

Grey

Across the entire grapheme set 'Grey' was chosen by controls 4.3% and by synesthetes 4.9%. Figure 2-11 shows the frequency distributions for all letters.

A significant association for grey with the letter X for both groups was found replicating the Rich et al., (2005) study. We also replicated that there are significant associations for grey with zero and Z for controls. We did not replicate the finding that grey was associated with U, for controls, though it is a top 5 choice in our sample, or 2 in the synesthete group. The comparison is listed in Table 2-3.

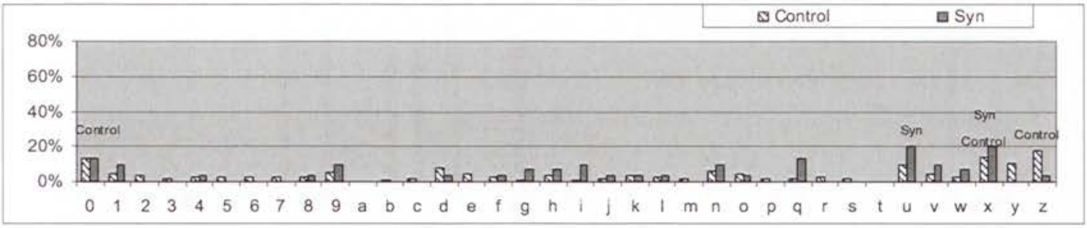

Figure 2-11. The frequency distributions of 'Grey' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour

Grey	**Rich et al., (2005) Synesthetes**	**Synesthetes**	**Rich et al., (2005) Controls**	**Controls**
2	Trend	*	0 Not assessed	0
U	Top 3	Significant	Significant	Top 5
X	Significant	Significant	Significant	Significant
Z			Top 5	Significant

Table 2-3. Comparison of significantly associated Graphemes for 'Grey' for both synesthetes and controls. Compared to the Rich et al., (2005) data
* denotes that the result is not consistent between the studies.

Red

Across the entire grapheme set 'Red' was chosen by controls 6.6% and by synesthetes 10.1%. Figure 2-12 shows the frequency distributions for all letters.

We replicate the significant associations found in the Rich et al., (2005) for the letters A and R with red for both synesthetes and for controls. We do not replicate the results for the number 4 though red is a popular choice in our study and we see an additionally significant association for the letter M which is a top 3 popular choice in the Rich et al., (2005) study. The comparison is listed in Table 2-4.

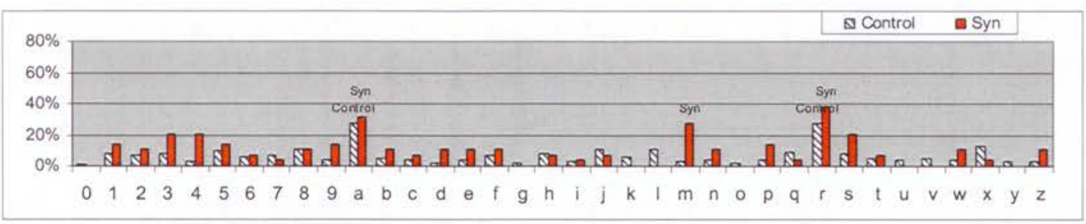

Figure 2-12. The frequency distributions of 'Red' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour

Red	**Rich et al., (2005) Synesthetes**	**Synesthetes**	**Rich et al., (2005) Controls**	**Controls**
4	Significant	Top 6		
A	Significant	Significant	Significant	Significant
M	M Top 3	Significant		
R	Significant	Significant	Significant	Significant

Table 2-4. Comparison of significantly associated graphemes for 'Red' for both synesthetes and controls. Compared to the Rich et al., (2005) data

Green

Across the entire grapheme set 'Green' was chosen by controls 26.7% and by synesthetes 13.5%. Figure 2-13 shows the frequency distributions for all letters.

This produces a large disparity between the groups. It may reflect the fact that green is an easy colour to generate spontaneously when asked to list colour names (Van Overschelde, Rawson, & Dunlosky, 2004). There is a significant association for both groups for the letter G which was a trend for synesthetes in the Rich et al., (2005) study and there is no significant association for the letter F to be green for controls which was a significant association in the Rich et al., (2005) study, though it is a top 5 popular choice. The trend for 3 to be green for synesthetes found in the Rich et al., (2005) sample was not replicated in our study although it was the second most popular choice. The comparison is listed in Table 2-5.

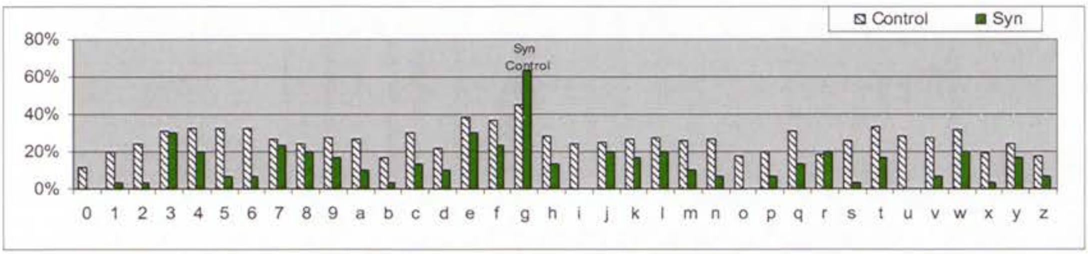

Figure 2-13. The frequency distributions of 'Green' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour

Green	Rich et al., (2005) Synesthetes	Synesthetes	Rich et al., (2005) Controls	Controls
3	Trend	Top 2		
F			Significant	Top 5
G	G trend	Significant	Significant	Significant

Table 2-5. Comparison of significantly associated graphemes for 'Green' for both synesthetes and controls. Compared to the Rich et al., (2005) data

Blue

Across the entire grapheme set 'Blue' was chosen by controls 33.4% and by synesthetes 18.9%. Again this is a significant disparity, likely reflecting the ease of generation of the colour blue (Van Overschelde et al., 2004). Figure 2-14 shows the frequency distributions for all letters.

Only controls show a trend for B to be blue and both groups show a significant association for blue 2s. This replicates the Rich et al., (2005) study for controls but not for synesthetes. There is an additional significant association for controls to associate the letter I with blue - this is in contrast to the letter I being significantly associated (perhaps phonetically) with white in the Rich et al., (2005) study. The comparison is listed in Table 2-6.

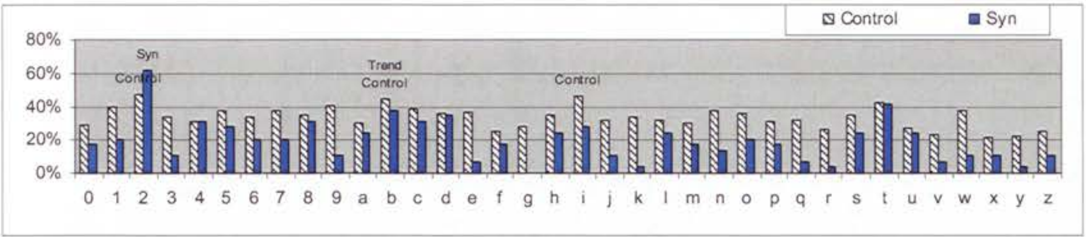

Figure 2-14. The frequency distributions of 'Blue' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour.

Blue	**Rich et al., (2005) Synesthetes**	**Synesthetes**	**Rich et al., (2005) Controls**	**Controls**
2	Top 2	Significant	Significant	Significant
B	Significant	Top 3	Significant	Trend
I	Top 2	Significant		

Table 2-6. Comparison of significantly associated graphemes for 'Blue' for both synesthetes and controls. Compared to the Rich et al., (2005) data

Pink

Across the entire grapheme set 'Pink' was chosen by controls 4.8% and by synesthetes 6.1%. Figure 2-15 shows the frequency distributions for all letters.

Our results replicate the Rich et al., (2005) finding for the letter P to be significantly associated with pink for both groups. We did not replicate a trend for the number 6 to be pink for controls nor did we find a significant association for synesthetes for the number 3 nor the letter C to be pink. We found a significant association for the letter K with pink for synesthetes which does not appear to be a top 5 choice in the Rich et al., (2005) sample. The comparison is listed in Table 2-7.

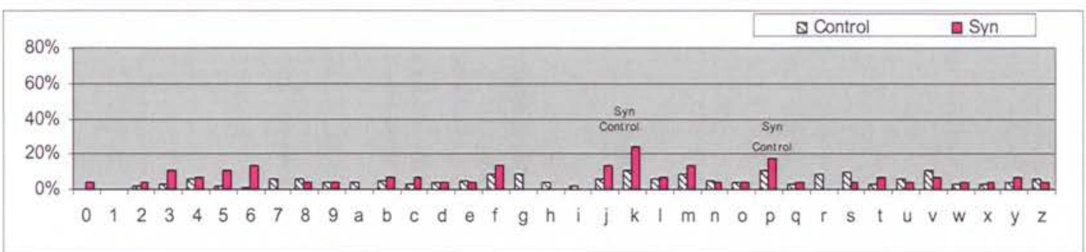

Figure 2-15. The frequency distributions of 'Pink' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour.

Pink	Rich et al., (2005) Synesthetes	Synesthetes	Rich et al., (2005) Controls	Controls
3	Significant	*	Trend	
C	Significant	*		
K	Top 5	Significant	*	Significant
P	Significant	Significant	Significant	Significant

Table 2-7. Comparison of significantly associated graphemes for 'Pink' for both synesthetes and controls. Compared to the Rich et al., (2005) data
* denotes that the result is not consistent between the studies.

Orange

Across the entire grapheme set 'Orange' was chosen by controls 3.6% and by synesthetes 9.5%. Figure 2-16 shows the frequency distributions for all letters.

Our results differed from Rich et al., (2005). For the letter J, we did not find either a trend or association for synesthetes though it is a top 5 popular choice, nor did we see a trend for the number 6 in controls. In our sample 7, N and V were significantly associated with orange for our synesthete group, with only V not appearing to be a popular choice in the Rich et al., (2005) study. We found a significant association for the letter O and orange for controls which does replicate the Rich et al., (2005) study. The comparison is listed in Table 2-8.

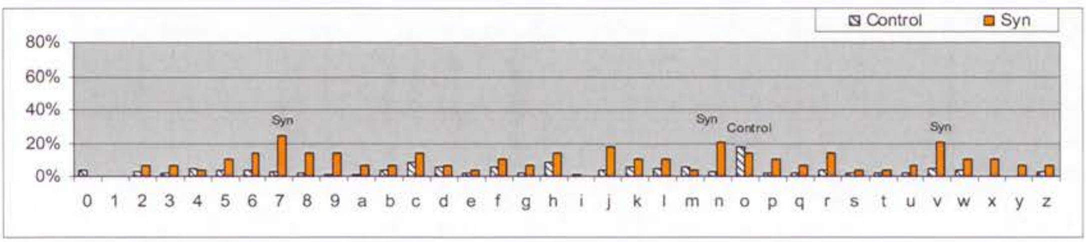

Figure 2-16. The frequency distributions of 'Orange' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour.

Orange	Rich et al., (2005) Synesthetes	Synesthetes	Rich et al., (2005) Controls	Controls
7	Top 2	Significant	Trend	
J	J	Top 5		
N	Top 5	Significant		
O			Significant	Significant
V	*	Significant		

Table 2-8. Comparison of significantly associated graphemes for 'Orange' for both synesthetes and controls. Compared to the Rich et al., (2005) data
* denotes that the result is not consistent between the studies.

Yellow

Across the entire grapheme set 'Yellow' was chosen by controls 5.2% and by synesthetes 12.7%. Figure 2-17 shows the frequency distributions for all letters.

Our result replicated Rich et al., (2005) for the letter Y for both controls and synesthetes. We did not find a trend for synesthetes for yellow Cs nor for controls to have either a significant association or trend for L or the number 5. We found that synesthetes had a significant association for the letter S to be yellow which was also a popular but not significant choice in the Rich et al., (2005) study. The comparison is listed in Table 2-9.

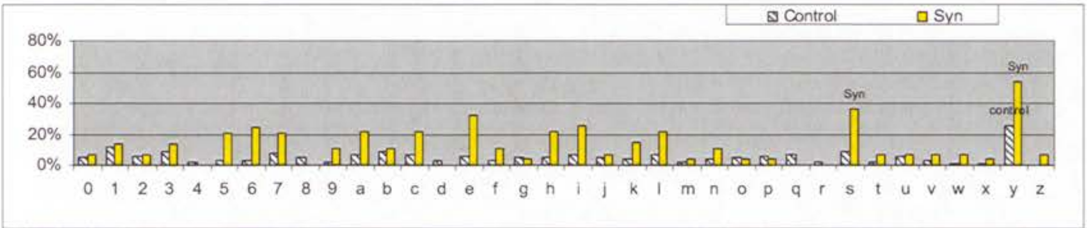

Figure 2-17. The frequency distributions of 'Yellow' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour.

Yellow	**Rich et al., (2005) Synesthetes**	**Synesthetes**	**Rich et al., (2005) Controls**	**Controls**
5			Significant	*
C	Trend	*	Significant	*
S	Top 3	Significant		
Y	Significant	Significant	Significant	Significant

Table 2-9. Comparison of significantly associated graphemes for 'Yellow' for both synesthetes and controls. Compared to the Rich et al., (2005) data
* denotes that the result is not consistent between the studies.

Purple

Across the entire grapheme set 'Purple' was chosen by controls 7.8% and by synesthetes 7.6%. Figure 2-18 shows the frequency distributions for all letters.

We replicated the results of Rich et al., (2005) with a significant associations of purple with V for synesthetes but not controls. Additionally we found significant associations for controls for the letter M and for Q and Z for synesthetes which are popular but not significant associations in the Rich et al., (2005) study. We do not find a trend or significant association for the letter P to be purple though it is a popular choice. Interestingly, no numbers in our study nor the Rich et al., (2005) study are significantly associated with the colour purple. The comparison is listed in Table 2-10.

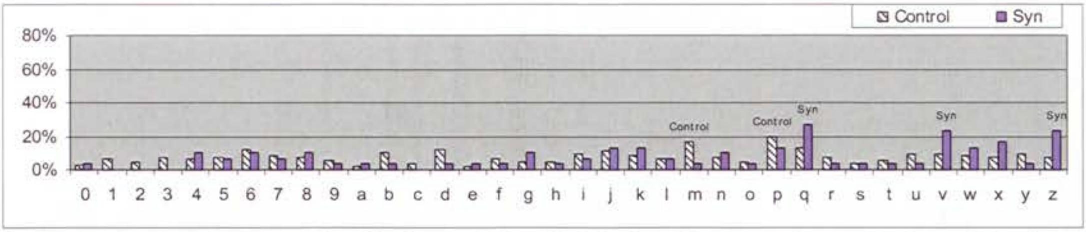

Figure 2-18. The frequency distributions of 'Purple' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour.

Purple	**Rich et al., (2005) Synesthetes**	**Synesthetes**	**Rich et al., (2005) Controls**	**Controls**
M			Top 3	Significant
P			Significant	Top 5
Q	Top 2	Significant		
V	Significant	Significant	Significant	*
Z	Top 5	Significant		

Table 2-10. Comparison of significantly associated graphemes for 'Purple' for both synesthetes and controls. Compared to the Rich et al., (2005) data
* denotes that the result is not consistent between the studies.

Brown

Across the entire grapheme set 'Brown' was chosen by controls 2.6% and by synesthetes 6.3%. Figure 2-19 shows the frequency distributions for all letters.

Unlike the Rich et al., (2005) study we do not replicate the findings for brown to be associated with 8 or H or show a trend for 9 for controls. We replicate the significant association for the letter D for synesthetes and not for controls. We find trends for synesthetes for the letters B, R and U which, while not significant in the Rich et al., (2005) study, are popular choices. We additionally find significant associations with the letters B and V for controls which were not found in the Rich et al., (Rich et al., 2005) study. The comparison is listed in Table 2-11.

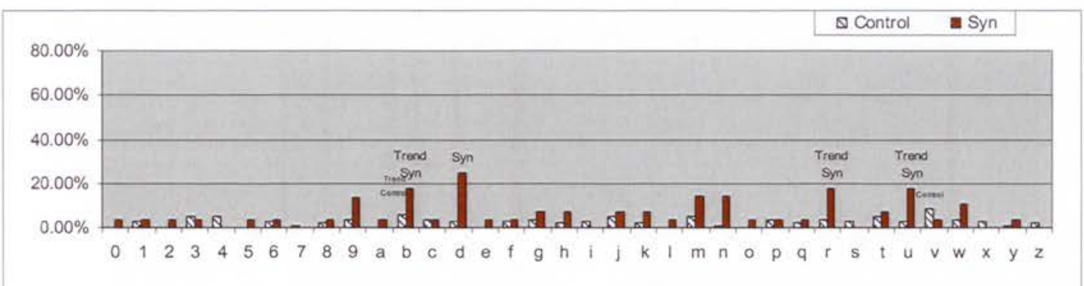

Figure 2-19. The frequency distributions of 'Brown' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour.

Brown	Rich et al., (2005) Synesthetes	Synesthetes	Rich et al., (2005) Controls	Controls
8			Significant	*
9			Trend	*
B	Top 2	Trend	*	Trend
D	Significant	Significant	Significant	*
H			Significant	*
R	Top 5	Trend		
U	Top 6	Trend	*	Significant

Table 2-11. Comparison of significantly associated graphemes for 'Brown' for both synesthetes and controls. Compared to the Rich et al., (2005) data
* denotes that the result is not consistent between the studies.

Achromaticity

Whether there were any graphemes likely to be achromatic (black, white, grey, no colour) for either group was examined. Across the entire grapheme selection an achromatic colour was chosen by controls 9.3% and by synesthetes 15.3%. Figure 2-20 shows the frequency distributions for all letters.

Both groups show a significant association for an achromatic zero. Synesthetes show a significant association for an achromatic X and controls for both X and Z. The data comes close to a trend for an achromatic number 1 for synesthetes. Again we note the similarities for the number zero and the letter O as well as the number 1 and letter I, indicating the influence of orthographic, phonetic or contextual similarity in grapheme to colour associations synesthesia. An issue we systematically investigate later in this thesis.

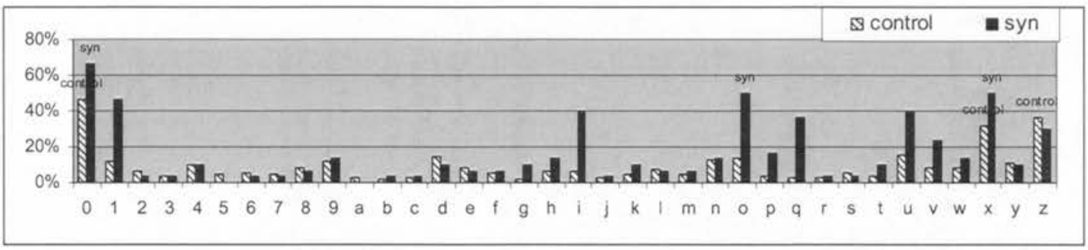

Figure 2-20. The frequency distributions of 'Achromatic' choices for synesthetes (coloured bars) and controls (striped bars). Significant associations are highlighted in the figure by showing the group name above the grapheme significantly associated with the colour.

2.3.1.3.6. Systematic Variability in Colour Match Consistency

We considered whether the internal consistency paradigm created any systematic variability in the data. First, we determined which graphemes had colour match consistency scores that varied most and least. We asked whether there was any uniformity in these results between synesthetes and controls. The question of whether earlier occurring graphemes are less variable (ordinality) was considered next and then the question of whether graphemes that occur more frequently (frequency) in the English language might be less variable in terms of colour match consistency.

Which Graphemes are Most and Least Consistent?

Table 2-12 shows the graphemes which have the highest and lowest average colour match consistency for both groups.

Lowest score Best Consistency	Lowest score Best Consistency	Highest score Poor consistency	Highest score Poor consistency
synesthetes	**controls**	**synesthetes**	**controls**
1	0	J	H
S	Z	V	K
R	Y	Z	T
0	R	T	I
C	A	N	5
A	X	H	2
O	Q	F	D
K	O	B	6
M	V	X	9

Table 2-12. List of top 25% of low colour match consistency scores for the graphemes (from lowest to highest consistency score) and bottom 25% high consistency scores for synesthetes and controls.

Notably Zero/0, O, A, and R are present in both samples as varying little. The low variability may well be due to the fact that these letters are most often white (0, O) or a typically strong Red (A, R). H and T are shared by both groups as being highly variable graphemes for colour choice.

Variability Due to Ordinal Position

The first test was based on the premise that synesthesia appears to occur in over learned sequences (Eagleman, 2009) and as such, variability scores might be tighter for graphemes earlier in the sequence (A,B,C vs. X,Y,Z), (0,1,2 vs. 7,8,9). The graphemes were split into letters and numbers so they could be tested in their correct category. Two statistical methods were used. First, a broad measure which discounts the value of the colour match consistency score by applying ranks was used. This replicated the method of Simner et al., (2005). Second, a different assessment was made by calculating the beta weights of a least square's regression. This replicated the method used by Eagleman (2009). The beta values were evaluated using a student t-test to determine whether they were significantly different to zero.

For Numbers

Figure 2-21 shows the mean colour match consistency scores for synesthetes and controls for numbers. A rank was assigned to each of the average colour match consistency scores for each number, from lowest to highest, for both synesthetes and controls. There was a significant effect of ordinal position on colour match consistency for synesthetes (Spearman's Rho (10df) = 0.71, p = 0.02) but not for controls (Spearman's Rho (10df) = 0.47 p = 0.17).

Figure 2-21. Mean and S.E. of GCAT colour match consistency scores for synesthetes and controls by numeric order. Error bars represent one S.E. of the mean

To ensure that this effect was not due to the influence of zero which was colour matched to 'no colour' or was achromatic, zero was removed from the analysis. No significant effect was then found for either group (Spearman's Rho (9 df) = 0.62, p = 0.08 for synesthetes and Spearman's Rho (9 df) = 0.27, p = 0.49 for controls).

The data were also examined using the statistical regression model. Each participant's colour match consistency scores for the set of numbers zero to nine was used to fit a least square's regression and a beta value was calculated for the slope of each line. The slope of the line was tested against whether it was significantly different from zero for each group. For the numbers zero to nine, both synesthetes (N = 29, M = 0.033, S.E. = 0.012, $t(28) = 2.66$, $p = 0.013$) and controls (N = 107, M = 0.063, S.E. = 0.014, $t(106) = 4.65$, $p < 0.001$) showed a significant effect of ordinal position on colour match consistency. Numbers occurring earlier in the sequence are more consistently colour matched than those which occur later.

After zero was removed from the analysis the beta values were reassessed. For the numbers one through nine, neither synesthetes (N = 29, M = 0.029, S.E. = 0.015) $t(28) = 1.948$, $p = 0.061$ nor controls (N = 107, M = 0.025, S.E. = 0.02, $t(106) = 1.608$, $p = 0.111$) colour match consistency is influenced by ordinal position.

In summary, after removing the number zero there is no indication that ordinal rank influences the colour match consistency of numbers by synesthetes or controls.

For Letters

Figure 2-22 shows the mean colour match consistency scores for synesthetes and controls for letters. The method of analysis described for numbers above was repeated. No correlation between alphabetical order and colour match consistency was found for synesthetes (N = 29, Spearman's Rho (26df), = 0.08, $p = 0.687$) but a significant negative correlation was found for controls, (N = 107, Spearman's Rho (26df), = -0.47, $p = 0.016$). Control participants were more consistent with their selections towards the end of the alphabet.

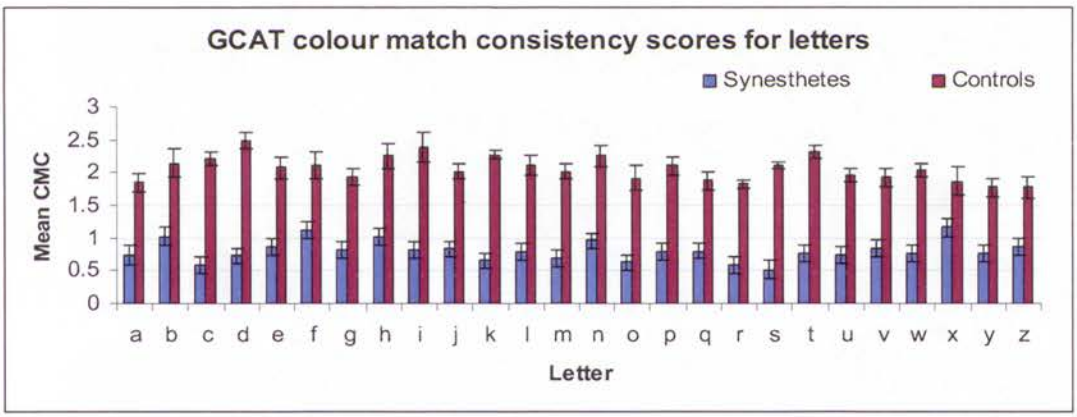

Figure 2-22. Mean and S.E. of GCAT colour match consistency scores for synesthetes and controls by alphabetical order. Error bars represent one S.E. of the mean

After calculating beta values, neither synesthetes (N = 29, M = 0.0004, S.E. = 0.004), $t(28) = 0.11$, $p = 0.91$) nor controls (N = 107, M = -0.006 S.E. = 0.003, $t(106) = -1.67$, $p = 0.096$) show a significant relationship between colour match consistency and alphabetical order. In summary, the two methods give different results as to whether alphabetical order has an effect on the consistency of colour matching.

Variability Due to Frequency of Occurrence in English

An alternative possibility of systematic effects on colour match consistency is that high frequency graphemes[6] are associated with lower variability. Figure 2-23 shows the colour match consistency scores in the frequency that they occur in English - from highest to lowest - for both groups.

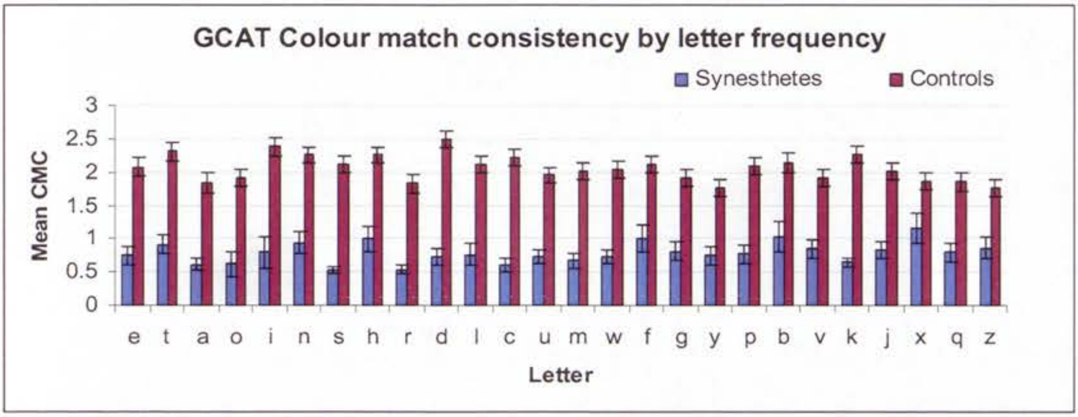

Figure 2-23. Mean and S.E. of GCAT colour match consistency scores for synesthetes and controls by order of frequency of occurrence in English. Error bars represent one S.E. of the mean

To examine the effect of letter frequency in English on colour match consistency both the letters of the alphabet and the colour match consistency score were ranked from lowest to highest, for synesthetes and controls. Neither the synesthete group (Spearman's rho (26df) = 0.074, p = 0.719) nor the control group (Spearman's Rho (26df) = -0.294, p = 0.145) show any trend to increasing or decreasing variability with frequency of letter use in English. After calculating beta values, neither the synesthete group (N = 29, M = 0.005, S.E. = 0.003, $t(28)$ = 1.693, p = 0.102) nor the control group (N = 107, M = -0.006, S.E. = 0.003, $t(106)$ = 1.8, p = 0.075) showed an effect of letter frequency on colour match consistency.

Finally, no grapheme-colour match consistency scores for synesthetes or controls were over 2 SD from the synesthete mean.

In summary, colour match consistency does not vary in a systematic way based on ordinal position or frequency of use for either group. No Grapheme is highly inconsistent or highly consistent suggesting that the GCATs stimulus presentation method does not bias colour match consistency results overall.

[6] The order of the frequency of letters used in English was taken from Simner et al., (2005).

Comparison with Simner et al., (2005)

Our second comparative analysis was made against the results of the published study of Simner et al., (2005). We tested whether colour associations for both groups were influenced by ease of generation, colour name frequency and entry into language.

Blue and green are extremely popular choices across the whole test, particularly for controls. 8% of control participants select blue more than 50% of the time and 11% select either blue or green more than 75% of the time. This presents a difficult problem for comparison with synesthetes as there appears to be a colour bias towards easily generated colours for controls, a finding indicated (but not significant) in the Simner et al., (2005) study.

Ease of Generation

The 11 colour categories used in the data (excluding 'no colour') were ranked according to their popularity and ease of generation both using the Battig & Montague (1969) norms and the updated version of these norms (Van Overschelde et al., 2004). The popularity of colour choices by each group was then ranked. Table 2-13 shows the ranking list:

Rank	**Colour category in ease of generation order**	**Synesthete popularity** Rank and percentage	**Control popularity** Rank and percentage
1	Blue	1st Blue (18.9%)	1st Blue (33.4%)
2	Red	4th Red (10.1%)	4th Red (6.6%)
3	Green	2nd Green (13.5%)	2nd Green (26.7%)
4	Yellow	3rd Yellow (12.7%)	5th Yellow (5.2%)
5	Purple	6th Purple (7.6%)	3rd Purple (7.8%)
6	Orange	5th Orange (9.5%)	8th Orange (3.6%)
7	Black	10th Black (3.8%)	10th Black (2.4%)
8	White	12th White (2.7%)	11th White (0.5%)
9	Pink	8th Pink (6.1%)	6th Pink (4.8%)
10	Brown	7th Brown (6.3%)	9th Brown (2.6%)
11	Grey	9th Grey (4.9%)	7th Grey (4.3%)
12	No Colour	11th No colour(3.8%)	12th No colour (2.0%)

Table 2-13. Colour Category in ease of generation for synesthetes and controls in the GCAT

Spearman's Rho was calculated for both groups. For both the synesthete group (Spearman's Rho = 0.818, p = 0.002) and the control group (Spearman's Rho = 0.736, P<0.010) the easier a colour was to generate the more appearances it made in the grapheme-colour letter set. This is consistent with the finding by Simner et al., (2005) for controls but not for synesthetes who showed no such trend in their study.

In short, colours which are easy to generate make more appearances in the coloured grapheme set of synesthetes and controls using the GCAT test.

We now look at only those grapheme-colour matches that are significantly associated with one another. We ask whether the factors considered in the Simner et al., (2005) study: a) ease of generation (Battig & Montague, 1969) and (VanOverschelde, 2004), b) the frequency of use of colour names in language (British National Corpus cited by Simner, 2005) and c) entry into language (Berlin & Kay, 1969) are influential in the significant colour associations of both groups. We consider this against alphabetical order (Table 2-14) and letter frequency (Table 2-15). The following questions are considered: i) is alphabetical order of significant colour matches determined by ease of generation, frequency of colour name use or entry into language. ii) are significant colour matches of high frequency letters determined by ease of generation, frequency of colour name use or entry into language. A table of results is shown below for ease of comparison against the outcomes in the Simner et al., (2005) study.

Alphabetical order	**Simner et al., (2005) Synesthetes**	**Synesthetes**	**Simner et al., (2005) Controls**	**Controls**
Ease of generation Battig and Montague (1969)	Not Significant	N = 22 Spearman's Rho = 0.064 *p* = 0.778 Not Significant	Near significant for forced choice controls otherwise Not significant	N = 16 Spearman's Rho = 0.431 *p* = 0.096 Not significant
Ease of generation updated Van Overschelde et al., (2004)	Not used	N = 22 Spearman's Rho = 0.028 *p* = 0.902 Not Significant	Not used	N = 16 Spearman's Rho = 0.515 *p* = 0.041 Significant
Colour name frequency in language/ Lexical frequency (British National Corpus cited in Simner et al., 2006)	Not Significant	N = 22 Spearman's Rho = 0.72 *p* = 0.751 Not Significant	Not Significant	N = 16 Spearman's Rho = -0.153 *p* = 0.573 Not Significant
Entry into Language Berlin and Kay (1969)	Not Significant	N = 22 Spearman's Rho = 0.147 *p* = 0.513 Not Significant	Not Significant	N = 16 Spearman's Rho = -0.074 *p* = 0.785 Not Significant

Table 2-14. Comparison of results with Simner et al., (2005) for synesthetes and controls. Significant associations by alphabetical order

We replicated the finding that there was no significant pattern of association for colour choices by alphabetical order, for colour name frequency or entry into language. We confirmed the near association for controls to use easy to generate colours for letters earlier in the alphabet when using the updated norms (Van Overschelde et al., 2004).

Letter Frequency	**Simner et al., (2005) Synesthetes**	**Synesthetes**	**Simner et al., (2005) Controls**	**Controls**
Ease of generation Battig and Montague (1969)	Not Significant	N = 22 Spearman's Rho = 0.235 *p* = 0.292 Not Significant	Not Significant	N = 16 Spearman's Rho = 0.546 *p* = 0.029 Significant
Ease of generation updated Van Overschelde et al., (2004)	Not used	N = 22 Spearman's Rho = 0.128 *p* = 0.570 Not Significant	Not used	N = 16 Spearman's Rho = 0.613 *p* = 0.012 Significant
Colour name frequency in language/ Lexical frequency (British National Corpus cited in Simner et al., 2006)	Significant	N = 22 Spearman's Rho = 0.234 *p* = 0.294 Not Significant	Not Significant	N = 16 Spearman's Rho = -0.113 *p* = 0.678 Not Significant
Entry into Language Berlin and Kay (1969)	Significant	N = 22 Spearman's Rho = 0.271 *p* = 0.222 Not Significant	Not Significant	N = 16 Spearman's Rho = -0.084 *p* = 0.758 Not Significant

Table 2-15. Comparison of results with Simner et al., (2005) for synesthetes and controls. Significant grapheme-colour associations by letter use frequency

Our results differ somewhat from the findings of Simner et al., (2005). We found that non synesthete participants allocated easy to generate colour names with frequently used letters. We did not find that synesthetes allocated colours to frequent letters on the basis of colour name frequency or entry into language. The studies differ in the method used to determine a significant association between a colour and a grapheme, and also in sample size (and therefore statistical power) with the Simner et al., (2005) sample being larger, having found more significant associations in the data.

2.3.1.3.7. Observations of Variability from Synesthete Performance

In this section, three sources of specific and idiosyncratic variability seen in the GCAT colour match consistency scores are discussed. The three sources were discovered through observation and interview with synesthetes after completion of the TOG. First, some graphemes may simply not have strong associations or have achromatic associations. Second, variability may be dependent upon how aware a person is of their synesthesia. If a synesthete is either unaware of their synesthesia or has not taken the time to explore it, they may not be able to describe or report on it accurately. Third, graphemes may have more than one concurrent or associated colour or have multiple uses, such as in musical notation.

Many synesthetes reported that zero and one were either transparent or achromatic - usually either black or white. On some occasions in the GCAT test they chose either one or the other, thereby inflating the total colour match consistency score. Figure 2-24 and Figure 2-25 show participant SS's grapheme-colour selections for testing sessions separated by 6.5 months.

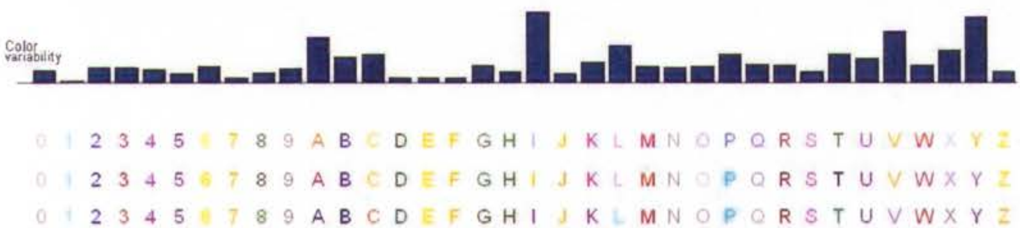

Figure 2-24. Screen display of GCAT data for participant SS. First testing session. Bar height indicates level of consistency. Tall bars indicate poor consistency.

Figure 2-25. Screen display of GCAT data for participant SS. Second testing session. Bar height indicates level of consistency. Tall bars indicate poor consistency.

Of particular interest are the letter A's data. SS reports that the letter A changes depending on what letters are around it. After an additional (third) follow up - 12 months after the second testing session, participant SS reported that letter A was probably more black than anything else. She also stated that she would most likely select the colour black consistently if asked to undertake the test in future. When asked about the source of the variation, she responded, "A has always been a source of confusion for me, its never really had its own identity".

The second source of variability exhibited by several synesthetes, including SS, was that they had not given a great deal of consideration to their associations and were not fully aware of them at the time of testing. From a strict point of view researchers might be tempted to dismiss such participants as unreliable or non synesthetes. However, in the case of SS, at least 22 of 36 graphemes are the same colour between the first testing session and the second which would certainly be enough to satisfy the Simner et al., (2006) criteria for inclusion in a synesthete group. This participant was aged 19 at the first time of testing and had never heard of synesthesia before participating in the experiments. She reported she had never considered synesthesia to be unusual and had never given it much thought. At the second meeting, SS reported that she had consulted with other family members and found several with synesthesia and was also much clearer about the associations after giving them some thought.

Two questions for future research are raised by this observation. First, what is special about some letters that they are most often achromatic? Second, why do some letters have strong and specific associations while others do not?

The third source of variability in colour match consistency arises when there is either more than one associated colour concurrent or the inducer has multiple interpretations. Figure 2-26 presents the participant EL's GCAT results, whose other concurrents to numbers are shown in Figure 5-5.

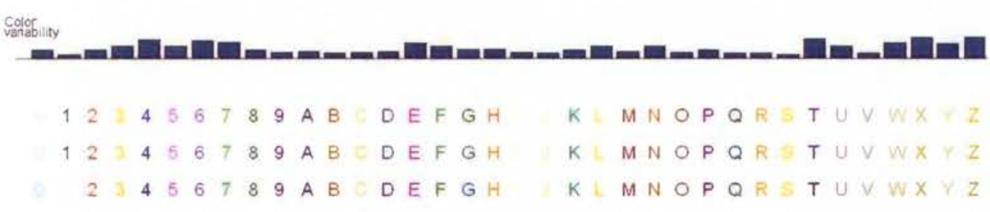

Figure 2-26. Screen display of GCAT data for participant EL. Bar height indicates level of consistency. Tall bars indicate poor consistency.

EL chose pink to represent the number 5, light blue for the number zero and blue for the number 4. Based on her interview and the illustrations subsequently provided (Figure 5-5), the number 5 could be represented by orange or pink, zero by no colour, white or blue and 4 by blue or yellow. A simple source of variability in these studies could therefore be attributed to the fact that correspondences as experienced can be one to many types which can lead to inconsistent or incomplete reporting as a single colour.

A final example is provided by a set of monozygotic identical twins from our study. The origin of the number associations is not known, but both twins report colour synesthesias for music, graphemes and words as well as odours. Many (but not all) of the colour associations are shared between the twins. For participant JS, the letter A is red except when played on the piano, when it is green, a fact that the participant spontaneously reported upon when seeing the results of her test. The high level of variability for the letter A in JS's test is therefore likely due to the multiple interpretations of the inducer (Figure 2-27). The other twin's (CS) result are shown for comparison in Figure 2-28.

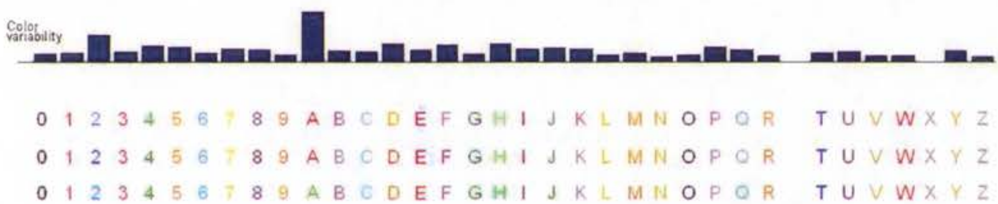

Figure 2-27. Screen display of GCAT data for participant JS. Bar height indicates level of consistency. Tall bars indicate poor consistency.

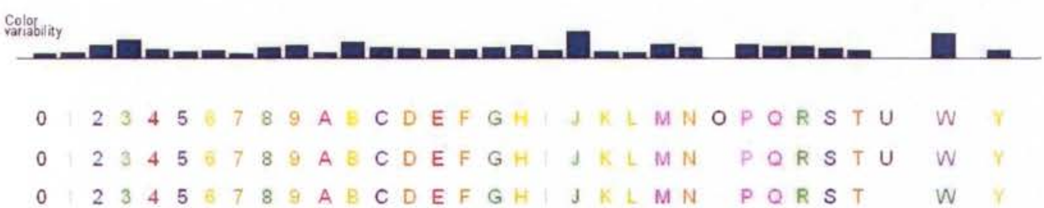

Figure 2-28. Screen display of GCAT data for participant CS. Bar height indicates level of consistency. Tall bars indicate poor consistency.

2.3.1.4. Discussion

The utility of the GCAT was evaluated against a group of self-referred synesthetes and a group of controls. It was found to differentiate these groups adequately for average colour match consistency as well as the proportion of consistently coloured graphemes.

For the diagnosis of synesthesia of an individual however, it was found to have weaknesses at the recommended colour match consistency score where a number of false positives were detected and false rejections were made. 6.5% of controls scored in the diagnostic range. For several participants this was achieved simply by selecting the same colour for a block of letters or numbers. Six synesthetes (four of twenty six self referred and two discovered) scored above the recommended score. This begged the question as to what the cut off boundary should be.

SDT was applied to the GCAT test and it derived three different colour match consistency scores that researchers could utilize depending upon what their research rationale is. If a researcher wishes to control completely for Type I error, a strict cut off of 0.7 could be used. Should a researcher wish to include all possible synesthetes in a sample then the score of up to 1.5 might be considered appropriate. The moderate sensitive diagnosticity score is found at score of 1.2. Scores over 1.2 should be treated with caution but do not necessarily imply that a self referred synesthete is in fact not a synesthete.

In the main, there is a strong level of agreement between the pattern of colour associations found in the internal consistency test and those reported by Rich, et al. (2005). This supports our earlier assertion that the internal consistency test is a good substitute for the retest consistency paradigm. The differences between the studies are slight in extent with few letters being significant or popular in one study and not in the other. There are few differences between the studies of letters being associated with the colour name initial, for example, W being white. Where there are differences between the studies, they are generally issues of magnitude (such as not reaching significance but being a popular choice). We can be confident that our sample was representative of idiopathic synesthetes as a whole and the GCAT has done a good job of extracting the colour choices of both groups. The GCAT therefore meets and extends the findings of previous research.

The use of the 'no colour' category is a small confound in any future data analysis as it may reflect an actual lack of an association or simply an association that is difficult to represent. The 'no colour' choice in the test may not give better and more reliable information about the synesthetes' actual experience. Consideration should also be given to a separate category named 'transparent'. There could be specific instructions on its use to ensure consistency between participants in future versions of the GCAT.

The finding that controls use easy to generate colours for letters earlier in the alphabet is particularly intriguing as the order of presentation of letters in the GCAT is completely random whereas Simner, et al. (2005) presented them in order. In the Simner, et al. (2005) paper, it is argued that the significant association between grapheme frequency and colour name frequency for synesthetes suggests that synesthetes are not producing associations "off the cuff" and that they are subject to environmental influences. We did not confirm this result. We believe that the difference between our findings and those of Simner, et al. (2005) might be due to a lack of power in our study. For example, we had fewer significant associations for each experimental group. There were 48 significant associations between graphemes and colours in the Simner, et al. (2005) study for synesthetes while there were only 22 in our study. There were also considerably fewer participants in our study (synesthetes: N = 28, controls: N = 107), than in the Simner, et al. (2005) study (synesthetes: N = 70, controls: N = 317). Finally, our significant associations between graphemes and colours were derived differently to the method used by Simner, et al. (2005) because we used the same method to determine them as the Rich, et al. (2005) study. The findings therefore require further replication.

Previously published studies using the TOG emphasise the consistency of responding by synesthetes, but fail to acknowledge the variability inherent in the reporting specific associations as well as in the experience of these concurrents. The investigations presented in this chapter revealed several sources of inherent variability, unrelated to the test paradigm. This indicates that subjective reports of synesthetes must be accounted for in diagnosis and serves as a reminder that while the TOG are an objective measure, they only measure one limited aspect of the synesthetic experience. In general, the GCAT is consistent with previously published research and while the TOG do discriminate between synesthetes and control groups adequately, they have some limitations for diagnosis of individuals.

2.3.2. Experiment 1b - Speeded Congruency Test (SCT)

The SCT is designed to be used with the GCAT for examining the genuineness of synesthesia. Its purpose is to confirm of the diagnosis of synesthesia.

2.3.2.1. Aims and Hypotheses

The specific aim of this experiment was to:

- verify the previously published results of this TOG (Eagleman et al., 2007),
- examine the diagnostic power of the test through the use of SDT.

The working premise is that the speeded congruency test can help accurately diagnose synesthesia at the recommended diagnostic score when used in conjunction with the GCAT. If so, then the following results will manifest:

- The SCT will distinguish between synesthetes and controls at the group level using a t-test.
- A large *d′* will be evident suggesting good separation between the distributions of synesthete and control group scores.
- Use of the test as an additional exclusion measure will reduce or eradicate the false alarms made at the recommended diagnostic GCAT score.

2.3.2.2. Method

The SCT examines how accurately a participant can state whether a grapheme is presented in a congruent or incongruent colour to the one that they chose in the GCAT. The SCT also measures the response time taken to do so.

2.3.2.2.1. Participants

10 grapheme to colour synesthetes and 37 controls were administered the SCT. Controls completed this test immediately after they completed the GCAT in the same testing session. Synesthetes completed the SCT on a different day and no earlier than a month from when they completed the GCAT. The test is thus skewed against the synesthetes.

2.3.2.2.2. Stimuli Presentation and Instructions

The thirty-six grapheme stimuli were presented for one second three times in random order for a total of one hundred and eight stimulus presentations. On half of the trials in the test the grapheme is presented in a congruent colour[7]. Participants were instructed to report as quickly as possible whether the screen colour of the grapheme presented was congruent with the one chosen in the GCAT by selecting from a yes / no dialogue box presented immediately after the stimulus. The dialogue box requires participants to record their response by mouse click over the words yes or no. The stimulus was presented against the same grey background used in the GCAT. Graphemes subtended approximately 3 degrees of visual angle (Verdana font).

2.3.2.2.3. Data Collection and Analysis

The data were collected automatically by the computer program. The percentage of accurate responses was calculated. Response time (RT) was also measured using the computer's internal clock.

2.3.2.3. Results

2.3.2.3.1. Group Analysis

Scores for synesthetes ranged from 78% to 96% correct. Scores for controls ranged from 46% correct to 97% correct.

Figure 2-29 shows that synesthetes (N = 10, M = 0.899, S.E. = 0.02), were more accurate in responding on the SCT than controls (N = 35, M = 0.706, S.E. = 0.02), $t(28.49) = 6.904$, $p = 0.001$). This replicates the findings of Eagleman (2007).

[7] In this version of the test, the SCT presents the letters either in the colour of the participant's choice or another from the trials against a grey surround. i.e. their congruent or incongruent synesthetic colour. This version of the test differs from that provided in the Matlab downloaded version of the Synesthesia Battery in that it does not use a coloured surround for the congruency but colours the letter itself. It is similar to the online version in this respect.

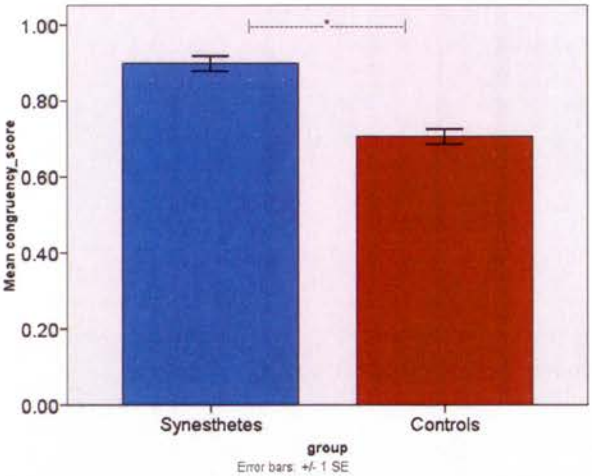

Figure 2-29. Mean and S.E. for accuracy in the speeded congruency test for synesthetes and controls. Error bars represent one S.E. of the mean. *indicates that the between groups t test was significant

Figure 2-30 shows that synesthetes (N = 10, M = 0.67, S.E. = 0.05) and controls (N = 35, M = 0.70, S.E. = 0.04) do not differ significantly in their response times $t(43) = -0.282$, $p = 0.779$. This result failed to replicate Eagleman's (2007) finding that synesthetes response times were faster than controls.

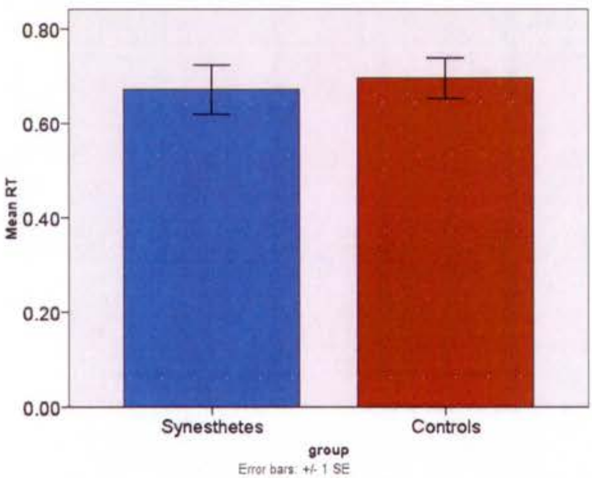

Figure 2-30. Mean and S.E. for RT of speeded congruency test for synesthetes and controls. Error bars represent one S.E. of the mean.

Eagleman et al., (2007) recommends a score of 90% as diagnostic. Only one control participant scored over 90%. This participant also achieved a GCAT score below 1 and was not a synesthete. This participant was retested on the SCT after an extended period and achieved only 45% accuracy.

With this one exception, the use of the GCAT and SCT together at the scores recommended by Eagleman et al., (2007) had perfect diagnostic accuracy.

2.3.2.3.2. SCT SDT Analysis

d' scores were calculated for this test in increments of 2.5% for all scores above 70%. This was completed in the same manner described for Experiment 1a: GCAT. The results are shown in Figure 2-31.

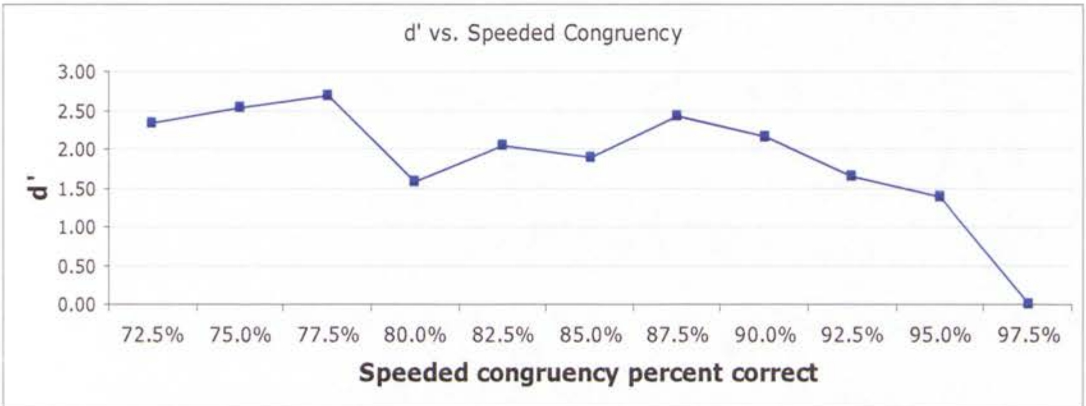

Figure 2-31 d' vs speeded congruency percent correct

Two main peaks can be seen in this graph. The first at 77.5%. This corresponds to the point where there are no false rejections. All synesthetes responded above this score. A number of control participants also achieved high accuracy scores, but only one over 87.5% where the second peak occurs. This is not materially different to the 90% recommended score of Eagleman et al., (2007).

2.3.2.4. Discussion

The SCT is simple and efficient to administer, takes approximately 4 minutes to complete. As a follow up to a grapheme TOG it would appear to be an effective way of increasing the diagnostic power of the decision of whether a participant is a synesthete or not.

The test has one limitation however that may affect its utility. It uses only exemplars from the second iteration of the GCAT and this is problematic if the participant has made selections in a number of different colour categories. For example, a participant may choose the following three colours for the letter A: red, blue, red. In this test the second choice would be taken as the correct response. When A is presented in red and the participant selects 'Yes' it is counted as an incorrect response when in fact the participant did choose that colour on the other two occasions. In this manner the test is biased in favour of synesthetes who by definition will give the same response three times. An improvement might be to adjust the design of the test so that only a colour category that was not used for that letter is presented in the incongruent condition.

The lack of RT difference between the groups in our study compared to that reported by Eagleman (2007) may be due to several reasons. First our synesthetes were not tested on the same day or time as that in which they undertook the GCAT, second, they are on average older or finally, the chosen response mode (mouse click) may not be sensitive enough. A possible improvement would be to use direct keyboard responses.

2.3.3. Discussion – Experiment 1

The rationale for conducting Experiment 1 was to assess the utility and diagnostic power of the internal consistency paradigm. The results presented in this chapter show that the internal consistency paradigm (as measured using the GCAT) can be confidently used as a tool for diagnosis of idiopathic synesthesia. Further, different diagnostic scores were identified to control for both Type I and Type II error. The paradigm is more effective when it is used in conjunction with the SCT. These results independently confirm the claims made by Eagleman et al., (2007).

With one exception in the sample of thirty seven control participants in the SCT, none scored lower than 1.2 in the GCAT and greater than 83% correct in the SCT together. Using a combination of the GCAT and SCT researchers can be confident of controlling for errors with the improved diagnostic scores identified in this study. Given the one outlier, conducting the SCT on the same day for control participants who have low colour match consistency scores (high consistency) in the GCAT may not necessarily assist in controlling for Type I error. If researchers wish to have perfect accuracy in diagnosis then administering the SCT in a delayed session may be more useful. Since the SCT takes roughly four minutes to complete and utilises the participant's own colour choices, it is an expedient way to confirm the durability of these associations over time. It also frees up the participant for other testing by not asking them to complete another lengthy matching task and provides an additional objective measure of the genuineness of any self referral as a synesthete.

Several sources of variability were identified by synesthetes in completing the GCAT. These stem from the fact that grapheme-colour synesthetes may experience multiple concurrent colours or that the grapheme may have different meanings in different contexts. Although it was not apparent that this variability had a substantive impact on the test results, researchers would do well to consider whether they dismiss a genuine synesthete on the basis of a GCAT score which lies at the boundary, because the score may reflect these types of influences.

In general the output of the GCAT is consistent with the published results of grapheme-colour retest consistency paradigm. It produces a similar result in terms of the number of graphemes which are consistently coloured and shows that synesthetes match colours to graphemes in ways that are similar to those published by Rich et al., (2005) and Simner et al., (2005).

Many control participants reported some kind of synesthesia or cross-modal associations in the basic screening checklist. This was borne out by the fact that many control participants can associate quite high numbers of graphemes with colours consistently. The GCAT provides an objective tool to measure and collect these associations and opens the door for testing whether and how these associations operate differently to those that are reported to be synesthetic in nature.

Key advantages in using the GCAT and SCT are:

- The tools are objective and reliable.
- The tests are not obviously confounded by categorical language or colour naming.
- The tool is portable. It can be used in any location where a computer is available or online which is currently being done by Eagleman (2009). This makes it easy and convenient to retest participants in remote locations or under circumstances which might not have otherwise been possible.
- Since the test utilises RGB values, it opens up new areas of research inquiry, such as; are there differences in colour choices between synesthetes and controls that are measurable in RGB space? Are there relationships between internal consistency and brightness or other variables?
- The GCAT establishes quite specific measures of a participant's colour selections. These are potentially useful as future stimuli for further psychophysical research or assessment. In that respect this test is superior to

the popular pencil and paper tests or those tests which have asked participants for the colour names of their associations.

- Where retest consistency over time is required the SCT is a simple and reliable way to conduct this assessment without infringing significantly on the participant's time.

Limitations of our assessment of the GCAT are twofold. A full test of the reliability of the GCAT would include a complete retest of each synesthete participant over time. This would provide a stronger assessment of the internal consistency paradigm against the retest consistency paradigm. Second, future use of the test should give more specific instructions to the control participants that effectively deals with their habit to choose the same colour and apply it to the grapheme stimuli consistently throughout the test. This would avoid high levels of low colour match consistency scores in controls and therefore might also reduce false detection rates.

2.4. Time Unit Induced Colour Synesthesia

Synesthetes report that they have specific colours for days of the week and months of the year. Many also report that these are arranged in specific spatial locations. To date there are no published studies using the internal consistency paradigm to test the colour associations of synesthetes to time units. The purpose of this experiment is to evaluate the utility of TOG for time-to-colour synesthesia using the internal consistency method with time words as inducing stimuli.

2.4.1. Experiment 2 - Time Unit Colour Association Test (TUCAT)

2.4.1.1. Aim and Hypotheses

The specific aims of this experiment are to:

- Administer the time unit to colour synesthesia test using the internal consistency paradigm and report the results.
- Determine whether the test differentiates a group of synesthetes from controls,
- Examine the diagnostic power of the test through the use of SDT.
- Derive the best colour match consistency score for the test that considers Type I and Type II errors.

- Evaluate the variation in the test scores due to different phenomenological aspects of synesthesia.

The working premise is that the internal consistency paradigm can accurately diagnose synesthesia at the recommended diagnostic score - a value under 1. If it is the case that the internal consistency paradigm is at least as useful as the retest consistency paradigm then the following results will manifest;

- The TUCAT will distinguish between synesthetes and controls at the group level using a t-test.
- A large *d′* will be evident suggesting good separation between the distributions of synesthete and control group scores.
- Any variability due to individual or idiosyncratic phenomenology will have no substantial impact on the sensitivity of the test.

2.4.1.2. Method

The TUCAT measures the consistency of RGB channel values for colours chosen on each of the three occasions that the weekday and month words were presented. In both the online and the downloaded version of the Synesthesia Battery the weekdays and months are presented separately.

In this experiment, both weekdays and months are combined into a time unit set. The rationale for testing the time units together (rather then weekdays and months separately) was the assertion put by Simner et al., (2006) that there might be a high number of false positives when testing for coloured weekdays alone, due to the small number of items in the test. This was found in our studies with pilot testing, and was also true when 4 iterations of the weekday stimuli were used instead of 3.

2.4.1.2.1. Participants

Sixteen grapheme to colour synesthetes and thirty two controls participated in this experiment.

2.4.1.2.2. Stimulus Presentation, Instructions and Data Collection

The stimulus presentation was similar to Figure 2-1 and instructions were similar to Experiment 1a, except that the word representing the weekday or month was shown instead of the grapheme. Words were presented in Helvetica font. Letters subtended approximately 3 degrees of visual angle. Participants were seated one metre from the screen. Responses were recorded automatically by the computer program. Stimuli remained onscreen until a response was recorded. Participants were asked to report a colour for each weekday or month word presented.

All twelve months and seven weekdays were presented in random order three times making a total of fifty-seven stimulus presentations. Data collection and analysis was conducted in the same manner as described in Experiment 1a.

2.4.1.3. Results

2.4.1.3.1. Group Level Analysis

For the synesthete group, scores ranged from 0.35 to 0.83. For the control group scores ranged from 0.46 to 3.49. All synesthete participants scored below the recommended diagnostic colour match consistency score of 1.0. No synesthetes would be falsely rejected at this score.

Of the thirty two control participants, seven (22%) scored below the recommended diagnostic colour match consistency score of 1.0. These controls would be falsely identified as synesthetes.

There was a significant difference in the colour match consistency scores between the groups. The synesthete group (N = 16, M = 0.57, S.E. = 0.04) showed stronger consistency in colour selection for each time unit than the control group (N = 32, M = 1.61, S.E. = 0.014). $t(36.5) = -6.87$, $p < 0.001$.

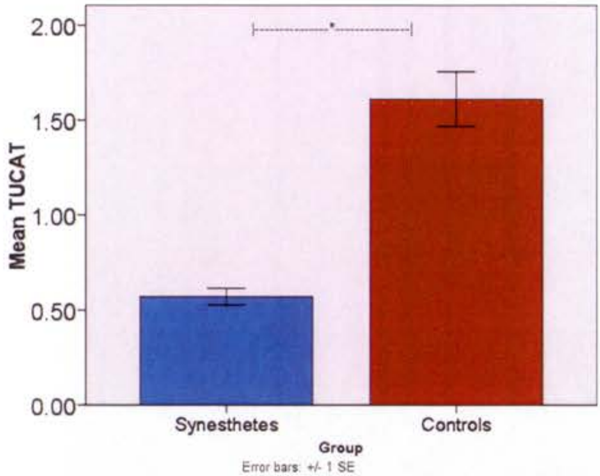

Figure 2-32. Mean and S.E. of TUCAT for synesthetes and controls. Error bars represent one S.E. of the mean. * indicates t test between groups reaches significance

The number of consistently coloured time units was also larger for the synesthete group (N = 16, M = 16.86, S.E. = 0 .44) than the control group (N = 33, M = 9.49, S.E. = 0.86), $t(43.12) = 7.68$, $p < 0.001$.

2.4.1.3.2. TUCAT SDT

A SDT analysis of TUCAT data was conducted in the same manner as that described for Experiment 1a. Synesthetes count as hits if they score below the colour match consistency score being assessed, and as misses if they score above it. Controls count as false alarms if they score below the colour match consistency score being assessed and as correct rejections if they score above that value. Figure 2-33 shows that the main peak of diagnosticity lies at 0.9/1.0 and falls away after that point.

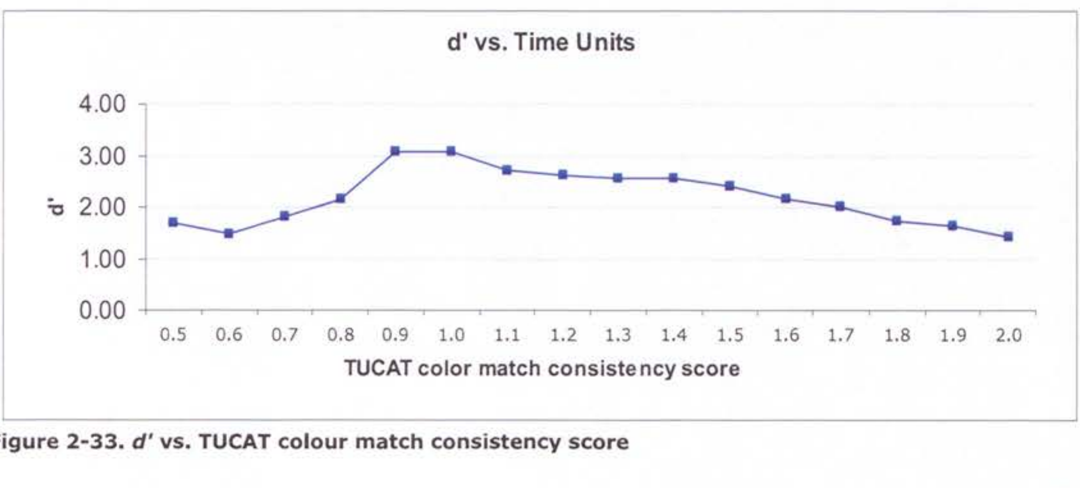

Figure 2-33. *d'* vs. TUCAT colour match consistency score

2.4.1.3.3. Observations of Variability from Synesthete Performance

Interviews with synesthetes who participated in this test revealed that they were unsure as to whether their colours for time units were unique to the time unit or influenced by the colours of their graphemes making up the name of the time unit word, often being a combination of both. Further, in our pilot testing, some synesthetes reported specific colour associations for only some time units and not others. The results of this TOG may be due to different underlying synesthetic associations and their interaction.

2.4.2. Discussion – Experiment 2

The internal consistency TUCAT reliably differentiates synesthete groups from control groups as measured by the independent samples t-test. Overall the diagnosticity of the test, measured in terms of subjective signal strength (*d'*), is adequate. A slightly stricter cut off of 0.9[8] for testing time unit to colour synesthesia may be warranted however. With regard to the control sample, 22% scored under the diagnostic score and would be falsely diagnosed as synesthetes. This only drops to 9% at a colour match consistency score of 0.8. This should raise some alarm about the test. This result might represent the ease with which colours are applied to categorical items. We noticed, for example, that a number of control participants born in the northern hemisphere selected cold colours for southern hemisphere summer months, thus effectively reducing 12 monthly categories to 4 seasons. On this basis scores which resemble those for synesthetes can be easily achieved. We note that the current online version tests months and weekdays separately and as such may be even more vulnerable to this type of problem.

Due to the fact that; a) many false alarms are detected at the recommended diagnostic score, and b) synesthetes report that different principles in the inducer - concurrent relationships influence their colour selections in the test (some colour matches are made on the basis of letters, some for the whole word), researchers cannot have a high level of confidence in the test paradigm as it currently stands. Importantly, it is also likely that the retest consistency paradigm suffers from the same limitations. This could be easily confirmed in laboratories who hold retest

[8] Since we derive the values in increments of 0.1 this is the diagnostic score. If we had derived our values as smaller increments, the actual value would be 0.83

consistency paradigm data currently. The development and implementation of a SCT for time units may help ameliorate this problem.

2.5. Auditory Induced Colour and Shape Synesthesia

Synesthetes report a variety of concurrent experiences for heard words, musical notes and environmental sounds. Indeed, the majority of the grapheme-colour synesthetes who participated in this collection of studies reported at least an occasional experience of colour for music or other sounds.

To date there is only one published study of musically induced colour synesthesia using a TOG (Ward, Huckstep, & Tsakanikos, 2006). There are no published studies using the internal consistency paradigm. Moreover, even though colour is considered to be the most commonly reported concurrent for heard stimuli, synesthetes have also reported shape and texture concurrents (Cytowic & Eagleman, 2009). This aspect of the experience was also noted by Ward, Huckstep et al., (2006) but was not explored. It has not been tested for consistency or durability in a TOG before. The computer code in the downloaded version of the Synesthesia Battery tests can be modified to include the collection of shape responses at the same time that colour concurrent responses are being collected. In this section we report on two experiments. We assess sound-colour and sound-shape synesthesia using two different classes of inducing stimulus. First musical notes are used as synesthetic inducers. Second, environmental sounds are used as inducers. Both of these experiments are based on similar tests that appear in the online version of the Synesthesia Battery[9]. In the tests reported here, both colour and shape were requested as responses.

2.5.1. Experiment 3 - Music to Colour and Shape Association Test (MCSAT)

The purpose of this experiment is to evaluate the utility of internal consistency TOG both for sound-colour and sound-shape synesthesia using musical notes and noise bursts as inducing stimuli.

[9] This test is not conducted here as originally provided in the downloaded version of the Synesthesia Battery. This test has been adapted from the sounds to colour test provided by Eagleman (2007) and we have simply substituted our own sample of sounds in the code running on Matlab. It is comparable to the current (2010) online version of the test which uses only 11 different synthesised musical notes.

2.5.1.1. Aims and Hypotheses

The specific aims of this experiment are to:

- Administer a music colour synesthesia TOG using the internal consistency paradigm and report the results.
- Examine the consistency of shape concurrents in synesthesia elicited by musical notes.
- Determine whether the test differentiates a group of synesthetes from controls
- Examine the diagnostic power of the test through the use of SDT.
- Derive the best colour match consistency score for the test that considers Type I and Type II errors.
- Compare and contrast the results of the internal consistency paradigm with the published results of the retest consistency TOG paradigm used by Ward, Huckstep et al., (2006).
- Evaluate the variation in the test scores due to different phenomenological aspects of synesthesia.

The working premise is that the internal consistency paradigm can accurately diagnose synesthesia at the recommended diagnostic score of 1.0. If the internal consistency paradigm is as useful as the retest consistency paradigm then the following results will manifest:

- The MCSAT will distinguish between synesthetes and controls at the group level using a t-test.
- A large d' will be evident suggesting good separation between the distributions of synesthete and control group scores.
- The test will give similar qualitative results to (or at least not be at odds with) the previous published studies of Ward, Huckstep, & Tsakanikos (2006) which used the retest consistency paradigm.
- Any variability due to individual or idiosyncratic phenomenology will have no substantial impact on the sensitivity of the test.

2.5.1.2. Method

The MCSAT was designed and conducted in the same overall manner as Experiment 1a. The MCSAT presents 44 musical notes and 5 noise bursts three times in random order making a total of 147 stimuli presentations.

Participants were asked to report both a colour and a shape association/concurrent for each sound presented on each occasion. Colour match consistency was calculated in the same manner previously described for the GCAT test. A measure of shape consistency was also derived by assigning one point if all three selections stated the same shape description. A zero score was awarded for any other combination. A total score of forty nine was possible. A list of 20 basic shapes was provided to all participants to facilitate their selections. These are listed in Appendix C.

Colour match consistency data was collected and analysed with the same method described in Experiment 1a. Shape data were automatically collected and scoring was conducted manually.

2.5.1.2.1. Participants

Fifty-one first-year control participants and twenty-eight synesthetes, (twenty of whom reported coloured synesthesia to sound stimuli including spoken words and music), were recruited for the MCSAT. We refer to these as sound-colour synesthetes. Thirteen synesthetes reported some experience of shape concurrents to sounds in addition to colour.

In the assessment of sound-colour synesthesia, there was a control group and two groups of synesthetes, those reporting sound-colour synesthesia and those without. Participants' scores were therefore assessed as three groups. In the assessment of sound-shape/form synesthesia, there was a control group and two groups of synesthetes, those reporting sound-shape synesthesia and those without.

2.5.1.2.2. Stimuli: Presentation and Procedure

Stimuli comprised forty-nine sounds including forty-four musical notes and five noise patterns. Musical sounds were drawn from the University of Iowa Musical Samples Database (Iowa, 2006). Each note is approximately two seconds long and was immediately preceded and followed by silence. Noise samples were produced using Goldwave (v4.16), and were also two seconds long. These were equalised to the same sound volume as the musical notes using Goldwave (v4.16).

The forty four notes were composed of ten sets of notes separated by musical fifths, from C1 to Eb6. This is the same note set used by Ward, Huckstep et al., (2006). The note set in this study comprised actual sounds not synthesised copies and as such comprised several different instruments for each pitch level because each instrument does not have the full pitch range. Stimuli were designed and presented using Matlab. Noises were White noise, Pink noise, Brown noise, Clicks, and a Pop and Hiss. Pink and brown noises have similar characteristics to white noise when heard by a listener but have slightly different spectral properties to white noise. Sound volume was 56db at source, and presented through speakers. Responses were recorded automatically by the computer program in the same way described in Experiment 1a.

2.5.1.2.3. Instructions

Participants were instructed to choose the colour that best matched the sound presented though the speakers. A single sound was presented along with a colour palette and colour selections were made by placing the cursor over the palette that appeared in the top left hand corner of the screen. Pressing the left mouse button selected the colour and a press of the keyboard space bar registered a final colour choice. Participants could also press the keyboard down arrow key to hear the sound for a second time. No further repeats of the sound stimuli were possible. Once that choice was made a small dialog box was presented and participants were asked to type in the name of the shape that best fit the sound played. Once selected the next sound was played.

2.5.1.3. Results

2.5.1.3.1. Group Analysis

Colour match consistency

Of the twenty sound-colour synesthetes only two scored less than 1 (10%). Scores ranged from 0.63 to 3.57. No non sound-colour synesthetes or control participants scored below 1. Their scores ranged from 1.04 to 3.05. If a colour match consistency score of 1 is used, this test fails to diagnose 90% of self referred sound-colour synesthetes.

A one way ANOVA revealed a main effect for group on colour match consistency score. $F(2,76) = 6.074$, $p = 0.004$. Post hoc analyses show that the sound-colour synesthete group (N = 20, M = 1.65, S.E. = 0.15) and the non sound-colour synesthete group (N = 8, M = 1.62, S.E. = 0.16) do not differ significantly from one another (Mean difference = -0.026, $p = 0.991$). The sound-colour synesthete group and the control group (N = 51, M = 2.05, S.E. = 0.06) do differ significantly from one another (Mean difference = 0.40, $p = 0.009$). Figure 2-34 shows the results. The difference between the non sound-colour synesthete group and the control group (Mean difference -0.43, $p = 0.069$) is quite close to the difference between the sound-colour synesthete group and the control group but it does not reach significance.

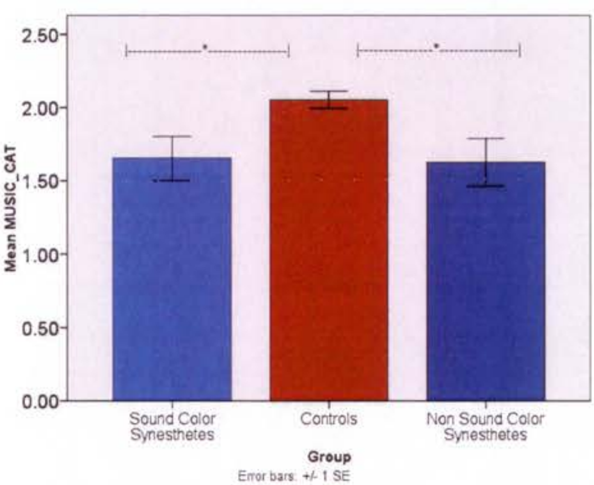

Figure 2-34. Mean and S.E. of MCSAT colour match consistency scores for controls and synesthetes with and without sound-colour associations. Error bars represent one S.E. of the mean, * indicates mean difference between groups reaches significance.

The number of consistent notes also differs significantly between the three groups as shown in Figure 2-35. $F(2,76) = 9.355$, $p < 0.001$). Post hoc analyses show that the sound-colour synesthete group (N = 20, M = 22.45, S.E. = 1.95), and the non sound-colour synesthete group (N = 8, M = 18.5, S.E. = 2.64) do not differ in their scores from one another (Mean difference = -3.95, $p = 0.432$). The non sound-colour synesthete group and the control group (N = 51, M = 13.92, S.E. = 1.00) do not vary significantly from one another (Mean difference = 4.58, $p = 0.258$), but the sound-colour synesthete group and the control group do differ significantly from one another (Mean difference = 8.53, $p < 0.001$).

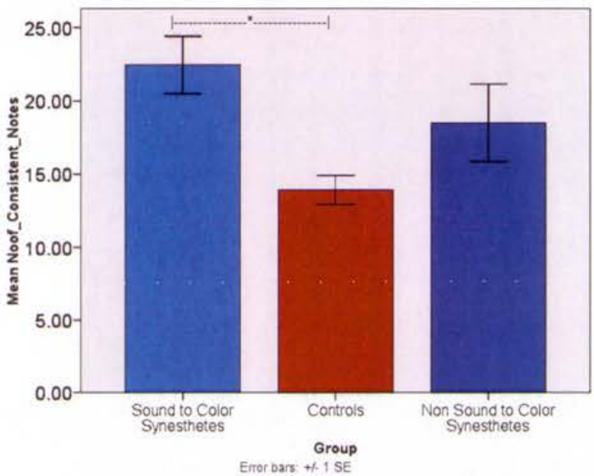

Figure 2-35. Mean and S.E. of number of consistently coloured notes in MCSAT for controls and synesthetes with and without sound-colour associations. Error bars represent one S.E. of the mean. * indicates mean difference between groups reaches significance.

Shape Match Consistency

A number of participants (across all groups) failed to complete this aspect of the test satisfactorily. Many participants either did not describe any shape associations in the test and of those who did, several only completed responses for a small proportion of the items. As such data for only 10 sound-shape synesthetes, 8 non sound-shape synesthetes and 36 controls were included in the results.

For the sound-shape synesthetes the number of consistent shape matches ranged from 1 to 38. For the non sound-shape synesthetes the number of consistent shape matches ranged from 1 to 24. For the thirty six control participants who did complete this aspect of the test, the number of consistent shape matches ranged from 1 to 24.

Utilising the same grouping strategy as above, a one way ANOVA was conducted between the three groups for musical notes shape match consistency. There was no significant difference in the total number of shape matches made between the groups ($F(2,52) = 1.33$, $p = 0.274$).

2.5.1.3.2. MCSAT SDT Analysis

A SDT analysis was only conducted for the MCSAT colour match consistency data. This analysis was conducted in the same manner as that described in Experiment 1a. The non sound-colour synesthetes and the control participants count as false alarms if they score below the MCSAT value being evaluated and correct rejections if they score above that value. Sound-colour synesthetes count as hits when they score below the value being assessed and misses when they score above that value.

Figure 2-36 shows the results of the analysis. Two peaks of sensitivity appear. The first at a score of 0.9 where no false alarms are detected. The second is at 1.6. After this point diagnosticity does not recover. All of the synesthetes (N = 12) that scored below 1.6 also reported colours for sounds other than spoken words and occasional musically induced synesthesia. These inducing stimuli were construction noises and other environmental sounds (birds chirping for example).

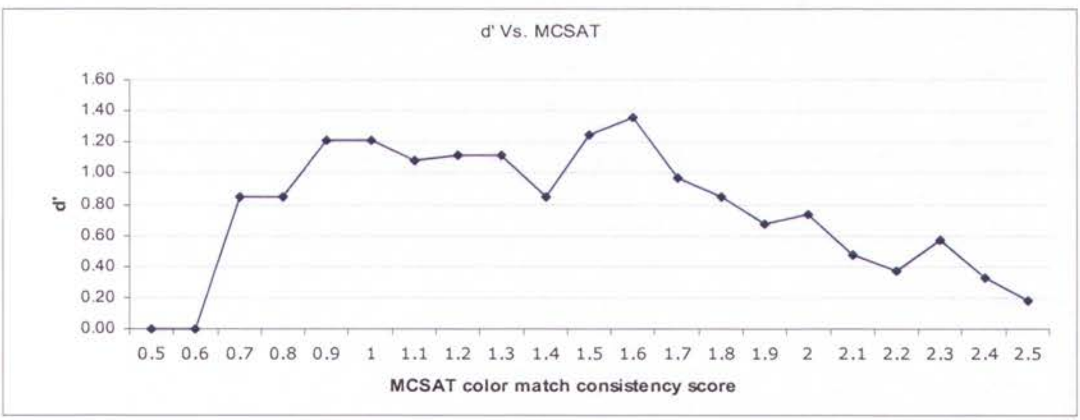

Figure 2-36. *d'* vs. MCSAT colour match consistency score

In terms of the overall diagnostic capability of the test, as measured by subjective signal strength, the highest *d'* values are quite low, especially when compared with those derived for the GCAT.

2.5.1.3.3. Comparison of Data with Ward, Huckstep Et Al. (2006)

In order to make a comparison (Ward, Huckstep et al., 2006) with the study the colour match RGB values of participants for each pitch were converted to HSV values in Matlab. Figure 2-37 and Figure 2-38 show the mapping of Value/Brightness and Figure 2-41 and Figure 2-42 show the mapping Chroma/Saturation for both groups for each pitch (collapsed for timbre) and noise bursts. Non sound-colour synesthetes are included in the control group in this assessment. All selections of 'no colour' by participants are excluded from the data set for this analysis.

Value/ Brightness

A 2 (group) by 10 (pitch) ANOVA was conducted. Pitch was found to influence Brightness $F(9,342) = 62.56$, $p < 0.001$) but there was no significant interaction $F(9, 684) = 0.87$, $p = 0.55$). Synesthetes and controls performed similarly in this aspect of the TOG. This result replicated the findings of Ward, Huckstep et al., (2006).

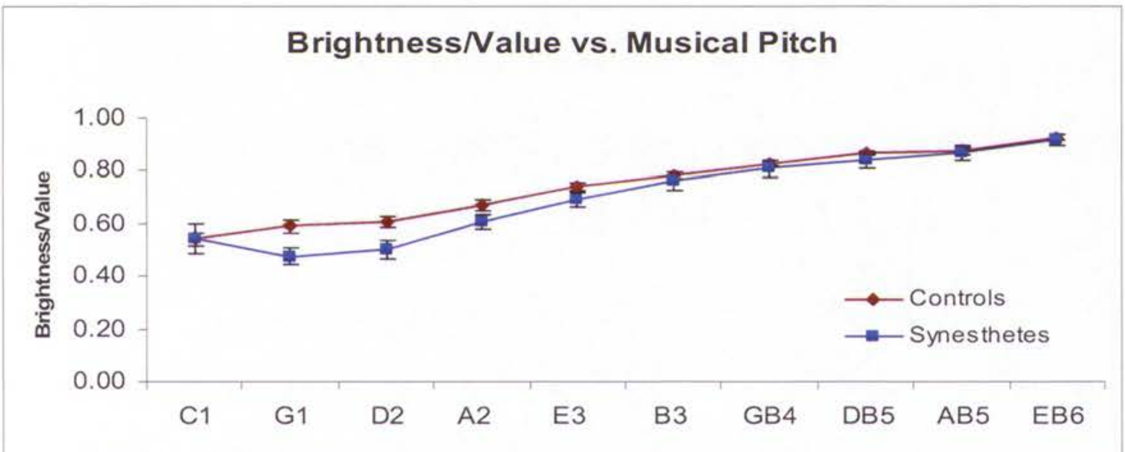

Figure 2-37. Mean and S.E. brightness by musical pitch for synesthetes and controls. Error bars represent one S.E. of the mean

In Figure 2-38, the brightness data for synesthetes and controls are given for noise bursts. There are no differences between groups in the way that brightness is allocated for each sound (all p values > 0.05).

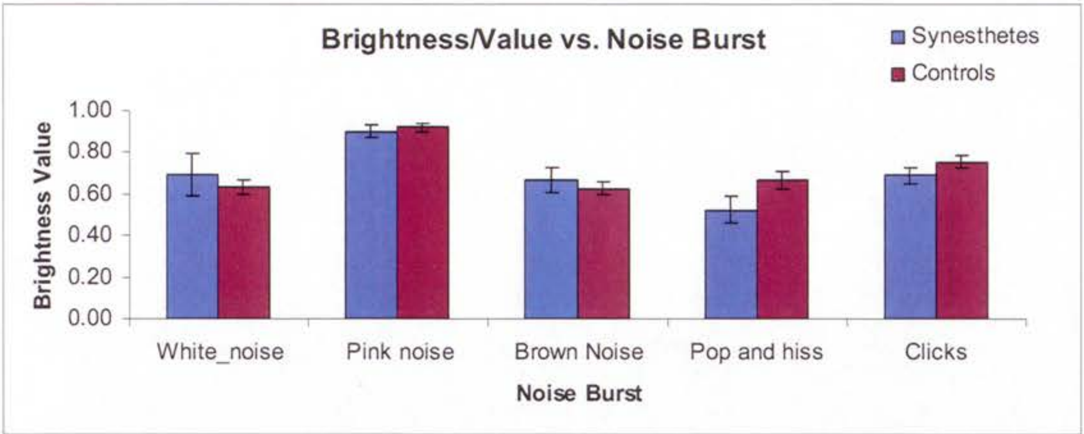

Figure 2-38. Mean and S.E. saturation value for noise bursts for synesthetes and controls. Error bars represent one S.E. of the mean

One benefit of using the Synesthesia Battery is that the output it produces is clear and informative (Figure 2-39). In the case of MCSAT it is easy to see when timbre or pitch to lightness relationships are elicited. Participant SW reports different synesthetic colours for musical instruments. These are grouped together in the output by instrument type then by increasing pitch. She shares with controls the trend for increasing saturation and brightness with pitch increases but differs from them in her ability to correctly identify and associate consistently a specific colour with an instrument.

Figure 2-39. Screen display of MCSAT results for participant SW showing colour selections for each musical note and noise bursts. Column 1 first selection, column 2 second selection, column 3 third selection

Chroma/Saturation

A 2 (group) by 10 (pitch) ANOVA was conducted. Pitch was found to exert an influence on saturation $F(9, 342) = 14.22$, $p < 0.001$) and this was different between the groups as the interaction between pitch and group on saturation was significant $F(9, 342) = 3.836$, $p = 0.003$)[10]. Figure 2-40 shows that the saturation increases at a lower rate for synesthetes than it does for control subjects. This did not replicate the result published by Ward, Huckstep et al., (2006) who found no such effect. Given the difference, future confirmation of this result is needed. Saturation levels of noise bursts for both groups appears in Figure 2-41. Two of the five noise bursts also appear to be less saturated for synesthetes than controls: White noise (Synesthetes (N = 18, M = 0.60, S.E. = 0.05); Controls (N = 53, M = 0.34, S.E. = .09), $t(69) = 2.49$, $p =$

[10] Mauchly's is significant so this is Greenhouse Geisser corrected.

0.015). Brown noise; (Synesthetes (N = 19, M = 0.56, S.E. = 0.05); Controls (N = 52, M = 0.29, S.E. = 0.08), $t(69) = 2.618$, $p = 0.011$). All other *p values*<0.05.

Importantly the overall trend for increasing saturation with increases in pitch is the same for both groups and does support the opinion put by Ward, Huckstep et al., (2006) that synesthetes and controls have similar strategies for mapping sounds to colours.

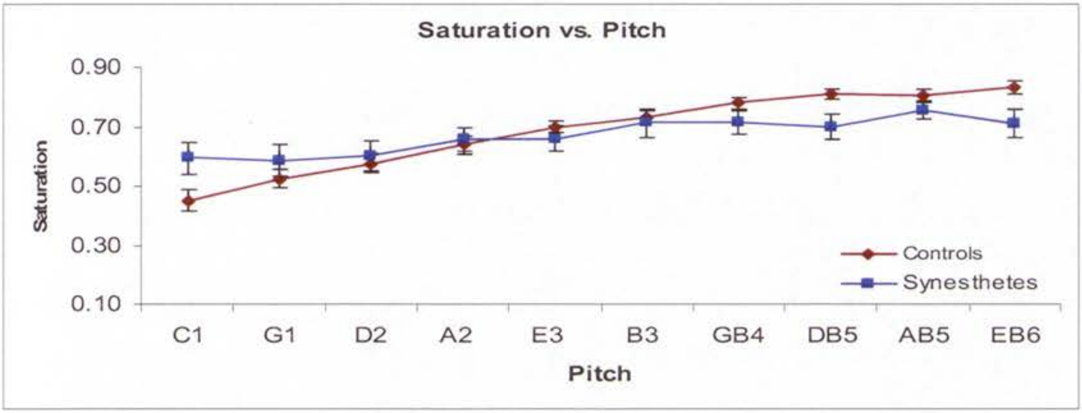

Figure 2-40. Mean and S.E. saturation values for each musical pitch for synesthetes and controls. Error bars represent one S.E. of the mean

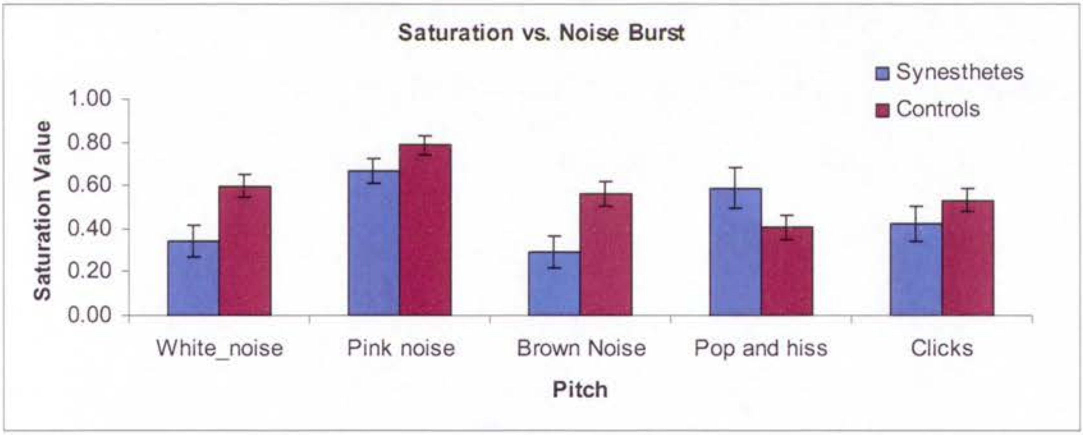

Figure 2-41. Mean and S.E. of saturation values for each noise burst for synesthetes and controls. Error bars represent one S.E. of the mean

Figure 2-42 shows that the trend for increases in saturation for increases in pitch holds when sine tones have been separated from the data for each group, especially at low pitches. In general, sine tones do appear to be less colourful than musical notes.

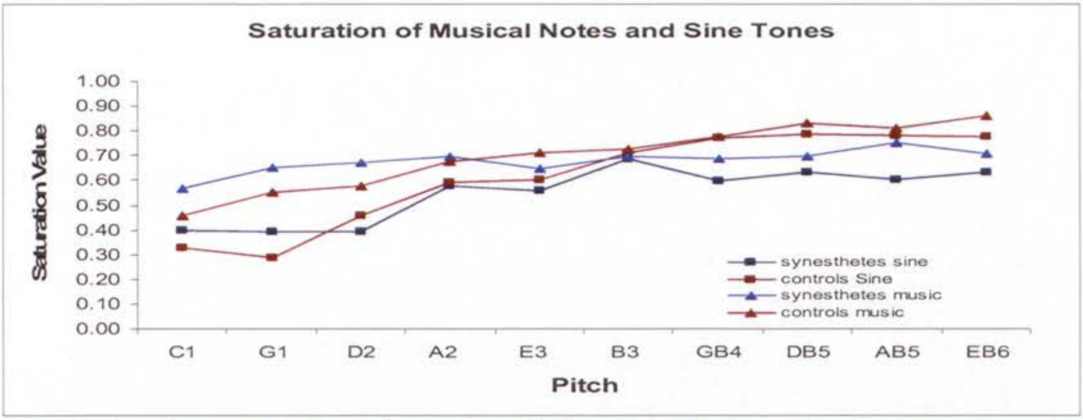

Figure 2-42. Mean saturation values of musical notes and sine tones for synesthetes and controls.

2.5.1.3.4. Observations of Variability from Synesthete Performance

Several synesthetes reported difficulty with different aspects of the task. Participant EL revealed difficulty in assigning colours or shapes correctly because her experience has multiple concurrents. Figure 2-43 below shows illustrations by participant EL representing various aspects of her music-colour experience. Pianos form blue or pink rectangles, pink when they are high pitched notes. String and brass instruments are wavy and have multiple colours and rock music is largely black with red triangular highlights.

Figure 2-43 Illustrations of EL's colour and form concurrents for music: Piano, Strings, Brass, Rock music

EL achieved a colour match consistency score of 1.44 which is below the second peak of 1.6. This score would not necessarily be considered diagnostic of synesthesia. Further, individual pitches are not always synesthetic inducers, and all high pitched notes when played loudly appear pink.

Synesthete participant DS is a trained conservatorium level musician who reports different colours and other concurrents for both instrument and pitch. A written inventory of her colour associations was taken approximately 6 months prior to her participating the MCSAT. Her performance on the MCSAT did not match her reported colours for either pitch or timbre particularly well and while her performance was relatively consistent from note to note, (colour match consistency score = 1.1) visual inspection of the data does not reveal any trend for colour choice for either pitch or timbre. DS reports very good relative pitch, but does not know if she has perfect pitch. It seems possible that the colour match consistency score of DS was affected both by the fact that she has multiple concurrents and by an inability to identify the specific pitch of the note.

A pair of identical twin musicians also participated in this test. Both twins report colours for musical experience and that their colour associations for notes are the same for the corresponding letters of the alphabet. These participants selected different colours in the MCSAT to those that would be expected on this basis. Even though their colour match consistency scores on the test were low (0.63, 1.16), suggesting good colour match consistency, the selections did not match their reported colour associations. Indeed one twin commented that she felt like she was guessing the colours toward the end of the test. In their case, colours appear to be elicited most often in production or playing, not as a one to one correspondence in a pure listening activity. Identification of the pitch of the note for the twins seems paramount to the ability to select the correct colour for it.

Since this TOG uses musical pitch as the synesthetic inducer, it would be anticipated that musical training would assist in performing this test. 5 professional musicians were participants in the synesthete sample. All 5 participants scored below 1.6, five of these below 1.2. ($N = 5$, $M = 1.16$, $S.E. = 0.16$). It seems likely that musical training bestows advantages in responding on this TOG.

2.5.2. Discussion – Experiment 3

The MCSAT separates groups of synesthetes from controls as measured by independent samples t-test of colour match consistency scores and shows that synesthetes do have more consistency in their colour matching to musical notes. If one delves a little deeper however, the SDT analysis reveals small *d'* values suggesting the diagnostic power of this test is low. There is no clear boundary where either Type I or Type II errors were fully accounted for which could be deemed satisfactory for use. It is also evident that at an individual level, researchers would not be able to use this TOG with confidence because the diagnostic power of the test at any individual score is very low. This is supported by the feedback on the test by synesthetes. This TOG does not appear to bring out the best consistency in reporting from a synesthete cohort, even for those who specifically report consistent pitch or timbre based colour synesthesias.

It seems clear that even though there may be differences in the extent to which pitch exerts an influence on colour saturation between the groups, synesthetes and controls appear to map saturation and brightness to pitch in similar ways. The findings of Ward, Huckstep et al., (2006) are generally replicated by our study which also has a larger sample of synesthetes and controls. The results of Marks (1989) are also replicated by demonstrating increasing saturation and lightness values for increases in pitch. The test therefore has reasonable consistency with previously published research. This suggests that it is not the internal consistency paradigm that is responsible for the low diagnosticity but may be a problem with the way the research question is posed for use of this test. This TOG appears therefore to be limited in its application.

The following possibilities may account for the low diagnostic power of the MCSAT;

First, the criteria for recruitment of sound-colour synesthetes was too broad for this test. This is a genuine limitation. However, the only other published study also appears to have a broad recruitment strategy.

Second, the consistency of colour matching in sound-colour synesthesia appears to be a more complex aspect of synesthesia to test than the consistency of grapheme to colour associations. This is likely due to the fact that there are a number of ways of manifesting the inducer - concurrent relationship; Timbre to colour, pitch to colour, interval to colour and style (country/rock) to colour are some of the more well known possibilities for music. Musical note identification also appears to be important for consistency colour matching in this test. Ward, Tsakanikos, & Bray, (2006) have previously shown that colours reported to be experienced for music often relate to written musical notes and not heard sounds. This suggests that this TOG may only be relevant for participants with highly specific pitch or timbre to colour correspondences and only if these elicit strong synesthesia consistently.

Third, the utility of the test also seems to be limited to the fact that synesthetes who report a lack of sound-colour synesthesia can also score in what might be considered a diagnostic range. This is curious and worthy of future scrutiny. The benefits of accurate strong colour sensitivity in grapheme-colour synesthesia found by Banissy et al., (2009) may extend to other types of synesthesia.

Fourth, sound-colour synesthetes may have multiple colour concurrents or different concurrents for pitch and timbre. This is especially true if synesthesia for music is based on music production or reading of musical notation.

Finally, synesthetes and controls undertake this task in similar ways. Both groups use the same inter-sensory translation principle (increasing pitch to increasing brightness and saturation) to map colours to the simple music and noise sounds presented in this test. This fact also implies that inter-sensory translation ability is not what makes idiopathic synesthesia distinctive. Performance in this test may not be the best way to diagnose sound-colour synesthesia.

From the standpoint of administration of this test in its Synesthesia Battery form, there are several benefits;

- it was simple to administer,
- the output makes visual identification of timbre and pitch relationships simple and obvious,
- it may have greater utility when testing only pitch or timbre colour synesthetes and particularly those who can identify notes when only heard.

In summary, the MCSAT appears to perform similarly to the retest consistency paradigm. It can separate groups of synesthetes from controls but does not have high diagnostic power.

2.5.3. Experiment 4 – Sound Colour and Shape Association Test (SCSAT)

The purpose of this experiment is to evaluate the utility of TOG for sound-colour and sound-shape synesthesia using the internal consistency method with environmental sounds as inducing stimuli. There is no previously published data or research on colours or shapes elicited by environmental sounds so this TOG cannot be assessed against the criteria set earlier in this regard.

2.5.3.1. Aims and Hypotheses

The specific aims of this experiment are to:

- Administer a general sound-colour synesthesia test using the internal consistency paradigm and report the results.
- To examine the consistency of shape concurrents in synesthesia elicited by general sounds.
- Determine whether the test differentiates a group of synesthetes from controls
- examine the diagnostic power of the test through the use of SDT.
- Derive the best colour match consistency score for the test that considers Type I and Type II errors.
- Evaluate the variation in the test scores due to different phenomenological aspects of synesthesia.

The working premise is that the internal consistency paradigm can accurately diagnose synesthesia at the recommended diagnostic score - a value under 1.0. If the internal consistency paradigm is at least as useful as the retest consistency paradigm then the following results will manifest:

- The SCSAT will distinguish between synesthetes and controls at the group level using a t-test.
- A large d' will be evident suggesting good separation between the distributions of synesthete and control group scores.
- Any variability due to individual or idiosyncratic phenomenology will have no substantial impact on the sensitivity of the test.

2.5.3.2. Method

The sound colour and shape association test (SCSAT) measures the variability of RGB values for colours chosen for environmental sounds. Stimuli comprised 47 sounds including animal noises, construction sounds and sounds made by people, such as laughing and coughing. All sounds were presented in random order three times making a total of 141 stimuli presentations. A low variability score indicates a high level of correspondence between the colours selected on each occasion.

2.5.3.2.1. Participants

20 first year control participants and 11 synesthetes (6 with reported sound-colour experiences) were recruited for the SCSAT. Participants' scores were assessed as three groups. There was a control group and two groups of synesthetes, those reporting sound-colour synesthesia and those without. 6 synesthetes reported sound-shape experiences.

2.5.3.2.2. Stimuli: Presentation and Procedure

The sound settings and stimuli presentation sequences were the same as that for the MCSAT settings. All sounds were derived from sound files found on freely available websites. They were selected for audibility and ability to be recognised, then equalised for sound level using Goldwave (v4.16) and cut to 1.5 seconds presentation time. Responses were recorded automatically upon selection in the same manner as described in Experiment 1a. A list of 20 shape names was also provided. Participants were asked to report their shape associations to each sound after selecting a colour for it.

2.5.3.2.3. Instructions

Instructions were the same as that for Experiment 3. Colour match consistency data was collected and analysed with the same method described in Experiment 1a. Shape data was automatically collected and scoring was conducted manually.

2.5.3.3. Results

2.5.3.3.1. Group Analysis

Colour Match consistency

The synesthetes scores ranged from 0.32 to 1.98. Of the 6 sound-colour synesthetes in the group, 5 scored less than 1. The synesthete participant who scored above 1 had difficulty with the task citing that after some time the sounds became all the same colour (red) and difficult to differentiate from one another. 83% of synesthetes are therefore correctly identified at the recommended diagnostic colour match consistency score of 1.0.

The control group scores ranged from 0.48 to 3.98. 2 of 20 (10%) control participants scored below 1.0 and would be falsely identified as synesthetes.

Figure 2-44 shows that there was a significant difference between the 3 groups ($F(2,28) = 4.44$, $p = 0.021$) in terms of colour match consistency. Post hoc tests showed differences only between the sound-colour synesthete group (N = 6, M = 0.94, S.E. = 0.23) and the control group (N = 20, M = 1.81, S.E. = 0.16), mean difference -0.88, $p = 0.027$. The non sound synesthete group (N = 5, M = 0.1.23, S.E. = 0.64) fell between both other groups and was not significantly different to either (Mean difference with the control group = 0.59, $p = 0.218$; Mean difference with the sound-colour synesthete group = -0.29, $p = 0.766$).

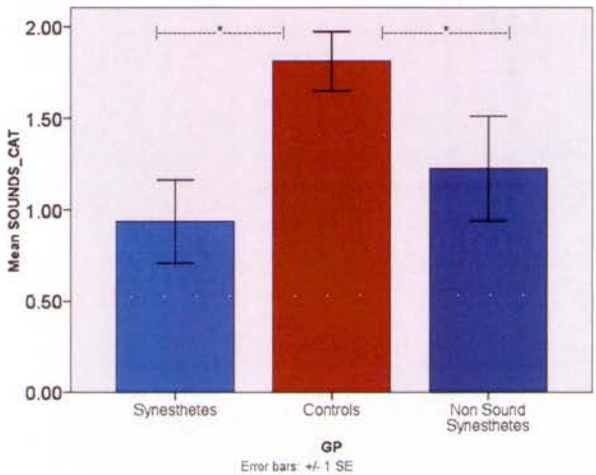

Figure 2-44. Mean and S.E. for SCSAT colour match consistency score for synesthetes, non sound synesthetes and controls. Error bars represent one S.E. of the mean. * indicates t test between groups reaches significance

Figure 2-45 shows that the number of consistently coloured sounds also differs significantly between the groups. ($F(2,28) = 7.62$, $p = 0.002$). Sound-colour synesthetes (N = 6, M = 31.00, S.E. = 4.16) have higher numbers of consistently coloured sounds than non sound-colour synesthetes (N = 5, M = 24.8 S.E. = 6.23) and controls (N = 20, M = 14.50, S.E. = 1.87). However, the only significantly different pairwise comparison was between sound-colour synesthetes and controls (mean difference = 16.5, $p = 0.03$).

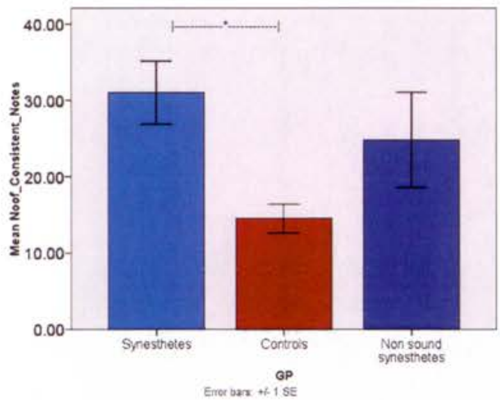

Figure 2-45. Mean and S.E. of the number of consistently coloured sounds in the SCSAT for synesthetes, controls and non sound synesthetes. Error bars represent one S.E. of the mean. * indicates t test between groups reaches significance

Shape Match consistency

Too few shape-to-colour synesthetes responded with a synesthetic association for a sufficient number of shape items in the test. Most control subjects complied with instructions but given the small number of synesthetes who report the experience of sound induced shapes, there was insufficient quality data collected to undertake any substantial analysis.

2.5.3.3.2. SCSAT SDT analysis

A SDT analysis was conducted for the sound-colour data only. The analysis was conducted in the same manner as that described in Experiment 1a. For the SDT analysis the sound-colour synesthetes are counted as hits when their score falls below the SCAT value being assessed and the remaining 5 non sound colour synesthetes are counted as false alarms when they score below the SCSAT value being assessed. Figure 2-46 represents *d′* values for the SCSAT test. Two peaks of sensitivity can be seen. The first is at a score of 1.0 the second at 2.0. Notably the first *d′* peak is at exactly the recommended diagnostic score. Also, the diagnosticity of the test as measured by subjective signal strength (*d′*) is higher in this test than the MCSAT suggesting that this might be a better test for diagnosis of sound-colour synesthesia.

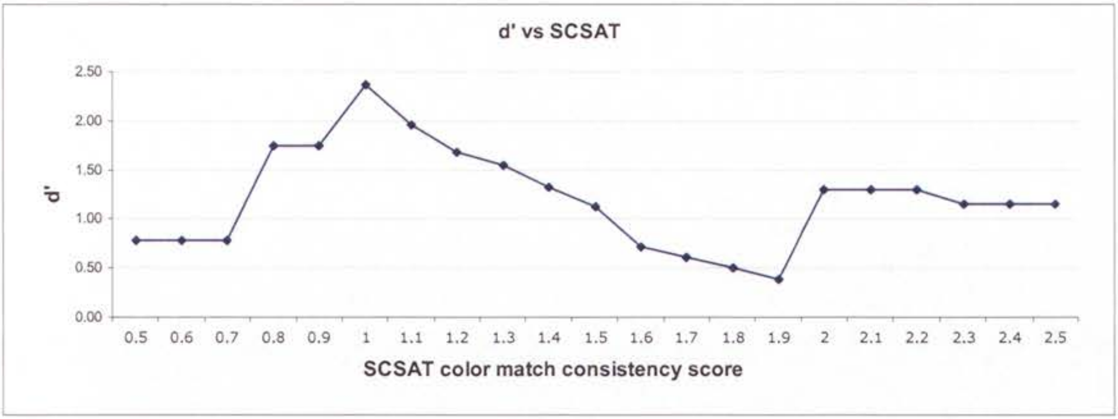

Figure 2-46. *d'* vs. SCSAT colour match consistency score

2.5.3.3.3. Observations of Variability from Synesthete Performance

Two synesthetes who report very specific and consistent colour and shape concurrents to environmental sounds reported that the test conditions were not conducive to the experience of synesthesia. Both also failed to record shapes for more than 50% of items in the test and one also reported multiple concurrent colours for several items in the test. This TOG appears to have fewer, but some qualitatively similar, limitations to the music colour test previously discussed.

2.5.4. Discussion – Experiment 4

This TOG, which uses sounds from the environment appears to have better diagnosticity than the musical note test for synesthetes who report coloured hearing as evidenced by its generally higher *d'* values. Possibly, this is due to the fact that the sounds are easier to distinguish and classify (baby crying, siren, thunder etc) than musical notes. It appears that the SCSAT would be a good addition to the Synesthesia Battery and may be helpful in assisting with the identification of sound-colour synesthetes from control participants. The utility of the test seems to be limited by the fact that synesthetes who report a lack of sound-colour synesthesia can also score in the diagnostic range. This might indicate that synesthetes have better memory (Yaro & Ward, 2007) or more specific sensory correspondences between modalities (Banissy et al., 2009).

2.6. General Discussion

In Chapter 1 we suggested that any new testing regime should be able to meet the following criteria. It should;

- be easy and efficient to administer,
- distinguish between synesthetes and controls,
- confirm previous findings – at least not be at odds with them,
- provide new insights on old problems, and
- create new opportunities for research.

Overall, the internal consistency paradigm for TOG assessed in this chapter and those that appear in the Synesthesia Battery, meet these criteria. The GCAT, SCSAT and SCT have the best diagnostic power as demonstrated by strong *d′* values. Despite its lower *d′* values the MCSAT still meets these criteria and has assisted in the provision of new insights in the area, such as the need to expand further the phenomenology of shape concurrents in synesthesia. For researchers who wish to use the TOG contained in the Synesthesia Battery, several tests have been improved through the identification of specific scores that can be used to adjust for sensitivity to Type I or Type II error. This bestows advantages for researchers who can decide to use either one for their research design.

The GCAT provides data which are consistent with previously published research and as such is not at odds with the retest consistency paradigm. Researchers can be confident that synesthete groups diagnosed by one TOG are sufficiently similar in their level and consistency of synesthesia to those diagnosed by another TOG. The GCAT's use with the speeded congruency test is advantageous because it enables an efficient assessment of the presence of synesthesia and assists in controlling for those who may be able to make consistent translations from one dimension to another but may not be able to recall them after a period. It is also a useful tool for verifying synesthesia at retest without the need for synesthetes to recreate their colour associations on a computer or via a written list.

The TOG results of Ward, Huckstep et al., (2006) for sound-colour synesthesia were in the main replicated. A curious finding was that the increases in saturation values for increases in pitch were flatter for synesthetes than for the control group in the MCSAT. We had no a priori assumptions that would predict this finding. It is an issue for future investigations and requires replication. Other than this finding, synesthetes and controls seem to perform the MCSAT in a similar manner. It was also observed that pitch or timbre identification is important in order to complete the test appropriately. This suggests that this test operates on two levels; one which is common to both synesthetes and controls (pitch to lightness and saturation) and one for colour - which is unique to synesthetes - but which is dependent upon correct identification of the inducing stimulus. Further research is required to tease this issue out, but this conclusion would be consistent with the conclusions in the literature on grapheme-colour synesthesia. Mattingley et al., (2006) argue strongly that correct identification of the inducing stimulus is required before synesthesia can occur. Further support for this suggestion is the fact that the SCSAT which used stimuli that were more informative, was much more sensitive to the differences between synesthetes and controls.

The TUCAT suffers from a high level of false alarms and even though the diagnosticity of the test was adequate, 22% of controls scored under the diagnostic score of 1.0 which was well over any acceptable level of Type I error. The internal consistency paradigm may not be the most sensitive testing method for this type of synesthesia. There is some ease to which colours are applied to simple categorical items, and this suggests the internal consistency method is limited in its utility. However, given the drastic reduction in false alarms provided by the concurrent use of SCT with the GCAT, the development of an SCT for time units would seem appropriate and may eradicate this problem.

With regard to the attempt to create a TOG for shape concurrents in synesthesia, it was found that this aspect of synesthesia is difficult to measure and may not be experienced as consistently or as strongly as colour. It certainly appeared to be more difficult to report consistently. A better phenomenological understanding of the relationships between inducers and shape concurrents may be necessary before TOG can be designed for this aspect of synesthesia.

One general criticism of the testing regime for consistency is that the test regime in itself is somewhat circular (Simner, 2010). Also as noted in the introduction, not all synesthetes report consistent one to one correspondences between inducers and concurrents, and the use of this test for diagnosis implies that those who do not report in this fashion (or demonstrate this ability in the test) are not synesthetes. Consistent synesthesias may only be one part of a much broader continuum. Disregarding inconsistent synesthetes in studies limits the potential these individuals can provide for a sound understanding of the condition. These facts are overlooked in the literature and need to be considered when designing psychophysical experiments. Further, the data also show that in each test a proportion of control participants are capable of making a large number of consistent colour matches from the inducing stimuli. Moreover, this capability does not appear to be unique to the internal consistency paradigm. For example, most publications report that they have used the synesthetes' colour associations when testing control participants in various experimental paradigms. This does have the advantage of ensuring that the same stimuli are presented to both groups of participants but fails to account for the fact that grapheme to colour synesthesia may simply be contextual and that some associations may be learned or common to both synesthetes and controls. In short, synesthetes may share with non synesthetic individuals aspects of a conceptual framework that associates colour with categorical items. This is a confound which can be avoided in psychophysical experiments by using the consistently matched colour associations elicited in these TOG for control participants as well as synesthetes. The fundamental difference between idiopathic synesthetes and controls may not be the presence of unique or idiosyncratic consistent associations of translations from one dimension to another but mainly (or only) in the perceptual consequences of these associations. Using the consistent colour matches of graphemes found in the TOG unique to each participant, this confound can be appropriately controlled in future experiments.

A final criterion that we suggested for any new test was that it 'open up new opportunities'. This appears to be occurring. The online version of the test is now being used by Eagleman (Eagleman, 2009) to examine trends in large sample of synesthetes and across cultures. Future studies can examine whether the internal consistency method offers any new insights into the grapheme-colour associations of our synesthetes simply because the variability of graphemes colour associations can be measured and the presence of matching patterns of associations using RGB values can be examined. This is a possibility that would not be available if categorical colour or a written colour name was the response medium.

In summary, both the internal consistency paradigm and therefore the TOG in the Synesthesia Battery meet the set criteria for improvements in test design and are a significant addition to the field.

3. WHAT ASPECTS OF GRAPHEMES DETERMINE SYNESTHETIC COLOUR CORRESPONDENCES?

3.1. Introduction

A key question of debate in the literature is what aspects of a grapheme induce synesthesia? (Ward & Mattingley, 2006). The debate centres around whether the physical form or the meaning of the grapheme is the inducer. Ramachandran & Hubbard (2001a) claim that the physical aspects of a grapheme, such as its shape, elicit the synesthetic experience of colour, on the basis that numeric dot patterns do not elicit synesthesia. There is also an argument that some grapheme-colour pairings may be hard wired. Spector & Maurer (2008) propose that "some colour letter mappings (O white, X black) are naturally biased by the shape of the letter, whereas others (A red, G green) may be based in literacy". In Chapter 3, it was reported that there were significant trends for both synesthetes and controls to select white for the letter O and black for the letter X and also to select red for the letter A, and green for the letter G. It seems that both synesthetes and controls might be sensitive to each of the influences proposed by Spector & Maurer (2008).

Myles, Dixon, Smilek, & Merikle (2003) showed that ambiguous grapheme forms elicited different coloured synesthetic associations depending on how they were interpreted. This suggests that the meaning and context of the grapheme and not its form are the drivers of synesthetic colour. It also suggests that recognition of the grapheme as a whole unit is required to elicit synesthesia. Dixon, Smilek, Duffy, Zanna, & Merikle (2006) have also shown that conceptual or contextual effects influence the perception of synesthetic colour by keeping the physical form of a grapheme stimulus constant across conditions and changing the context of the letters or numbers surrounding the stimulus. Synesthetes reported changes to the colour of the synesthetic percept depending on the context to which the grapheme stimulus was associated. In simple neural processing terms, Ramachandran & Hubbard (2001a) state that early visual features and the extraction of them are the causal basis of synesthesia. The findings of Dixon et al., (2006) as well as those of Edquist et al., (2006) imply that more sophisticated processing might be necessary.

If synesthesia is a conceptual rather than perceptual phenomenon then associative learning accounts may not be easy to dismiss. The idea that the grapheme-colour associations of synesthetes are learned is often rejected outright in the literature in favour of neurological explanations. However, as Marks & Odgaard (2005) rightly point out, graphemes are learned language units and so the contribution of associative learning and development to synesthesia must be considered. To our knowledge, there have not been any recent advances to associative learning theories of synesthesia. This is probably because many researchers believe the theory is fundamentally inadequate (Rich et al., 2005). One frequently cited reason why associative theories fail is that there is no reason or evidence to suggest that "children are exposed on hundreds or thousands of occasions to the same pairs of stimuli in different modalities" (Marks & Odgaard, (2005) - and also see Rich et al., (2005) for a similar claim). Another is argued by Ramachandran & Hubbard, (2001a) who assert that the effects of perceptual grouping, popout and crowding seen in synesthetes "prove conclusively" that synesthesia is sensory and "not an effect based on memory associations from childhood".

Idiopathic synesthetes report that they are not aware of where their synesthetic colours come from and believe that they were acquired implicitly. They recall having them since they were children. However, previously published research has shown that the colour associations to graphemes made by synesthetes are not completely random. There are linguistic and experiential factors that influence the associations made (Simner et al., 2005). Two published examples are of particular interest. First, Witthoft & Winawer (2006) present a case where a synesthete's grapheme-colour associations matched a fridge magnet set used in childhood suggesting that a child's play toy can be influential in the synesthetic colour associations to graphemes. Second, in a study of monozygotic twins Hancock (2006) describes twins with strong and enduring grapheme-colour associations evident at age 3. The origin of their colour number associations is known; a jigsaw that was played with in an early learning centre. It is also reported that the twins (T and R) were often both dressed in the same clothes except that they differed in colour. T would be dressed in green and R in blue. For both children at age 12, the synesthetic colours of the letters T and R are indeed green and blue, suggesting a personalised colour association pertaining to each individual. This could well be the result of exposure to hundreds or indeed thousands of occasions of paired stimuli and is therefore suggestive of an associative learning strategy. Interestingly, these are not the colours reported for R at age 6 years 7 months where the letter R is associated with red (for the child T) or with pink (for the child R). Synesthetes sometimes report that the colour associations for some graphemes do change over time. Further, Simner, Harrold, Creed, Monro, & Foulkes et al., (2009) claim that there is a "temporal gap between a complete knowledge of inducers, and the consistent neurological mapping of inducers to their sensory cross-modal concurrents". The criticism that children are not likely to be subjected to hundreds or thousands of stimulus pairings is falsifiable, not simply on the basis of the case study described above but also because there is further evidence of this type of association strategy in the surviving colour-grapheme sets of synesthetic adults.

The sort of patterns that would be seen in the grapheme-colour pairings of adults that would show deliberate or explicit effects of association might be; colour matching to personally relevant information; colour matching based on sequence position or colour matching based on ordinal position. We observed such effects in the data from the GCAT in Chapter 2. For example, several female synesthetes selected the colour pink for the first initial letter of their name. JEN whose uses the name Jenny, for example, has pink colour associations for J,N,Y. T is also pink and occurs in her actual first name, Jeanette. This might indicate explicit attentional or learning affects. It is possible that JEN could have seen her name written in pink letters throughout early childhood or have written it herself over and over. She claims to have changed the use of her name from Jeanette to Jenny in primary school. According to Thompson (2009), for children as young as 4 years the letters in their first name are given more attention and as such they are given priority in learning. Colour matching based on sequential position (AB, BC, CD) and for ordinal position A1, B2, C3 was also observed in both the synesthete and control data. The participant LE shows evidence of personal and sequential matching in Figure 3-1. LE has matched 2 with B and 3 with C suggesting some ordered sequencing or explicit colour matching strategy. He has also matched A and 4 which are orthographically similar and also with L, his first name initial.

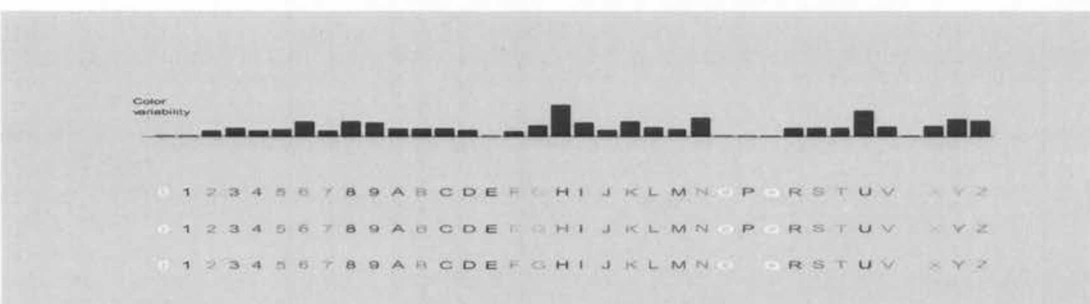

Figure 3-1. Screen display of GCAT results for participant LE. Shown against a grey background due to white letters. Bar height indicates level of consistency. Tall bars indicate poor consistency.

The presence of these colour matching patterns also suggests that colours are bound to whole grapheme units, and that colour matching to graphemes is likely to be influenced explicitly.

In this chapter our first analysis is to test whether the grapheme-colour sets of synesthetes show evidence of gender specific colour preferences in their first letter initials as well as ordinal or sequential colour matching at the group level. This would indicate that such associative learning activity (either implicit through visual exposure, or explicit though deliberate learning) does in fact take place broadly for synesthetes and not only in single cases.

Associative learning accounts might have more to contribute to explanations of synesthesia if they were brought into line with current theories of letter recognition and reading development. For example, using these theories as a framework, we may be able to break down the question about what characteristic of the inducing grapheme's orthography is required to elicit synesthesia and therefore deduce which aspect of the grapheme, a colour (or indeed other concurrent) is associated. Petit, Midgley, Holcomb, & Grainger, (2006) argue that there are 3 stages of letter processing and recognition: a) the extraction of sub-letter features, such as orientation and curvature; b) case specific representations; and c) case independent representations, commonly termed abstract letter units (ALUs). Each of these could form separate hypothetical units for the binding of colour to form in synesthetes.

Support for the existence of the first stage in letter processing comes from research by Fiset et al., (2008) who used the Bubbles Technique (Gosselin & Schyns, 2001) to determine the most important features for adults identification of letters. In their study it was demonstrated that it is not the overall shape of a letter which determines its identification but specific sub features of letters. Line terminations and horizontals are most important in letter identification (Fiset et al., 2009) and make a letter distinctive. If colour is bound to form in synesthesia and elicited at the sub feature level – and therefore before the full grapheme is recognised - then letters which share easily confusable features might also share their colours. This could be tested by examining grapheme pairs which are easily confusable to see if they share the same colour. If this is the case this should manifest more often in synesthetes than controls.

Polk et al., (2009) argue that "the visual system learns and uses letter representations that encode identity but that abstract away from visual appearance" to form ALUs. They argue that the acquisition of ALUs is due to the exposure of young readers to the presentation of letters in common contexts (for example, CAT, cat) where case and font changes occur. ALUs drive reading comprehension (Finkbeiner & Coltheart, 2009). By the time one is an adult, all letter forms have become ALUs and operate on a contextual basis in the reading process. It is possible that many previous studies of grapheme-colour synesthesia have been examining this stage in letter identification and processing making it highly likely that contextual effects were seen.

It was reported in Chapter 2 as part of the comparative analysis with the Rich et al., (2005) study that both 0, O and Q tended to be white and that 1 and I tended to be black. That orthographically similar graphemes share the same colour is not a new or unique observation. Day (2005) reported that synesthetes often have 5 and S coloured similarly but unfortunately did not provide any statistical data to support the statement. Day's (2005) assertion was drawn from his analysis of self-referred synesthete data (N = 172) but he does not report a comparative non-synesthete sample. Synesthete participant JEN, (Figure 3-2) provides a clear demonstration of colour matching for orthographic similarity. JEN matches 0, O, Q in white. In fact, with the exception of the letter F and those in her name (JNYT) all 36 graphemes seem divisible into colour groups where the graphemes in each subset share basic orthographic similarity (2,5,S – blue; 0OQ – white with C – a different but similar yellow-white; 1I – white; 3E – green; 6g (and possibly lowercase a) – yellow; 9P – black; KZW – black; BHR – brown; 8DUVX – grey).

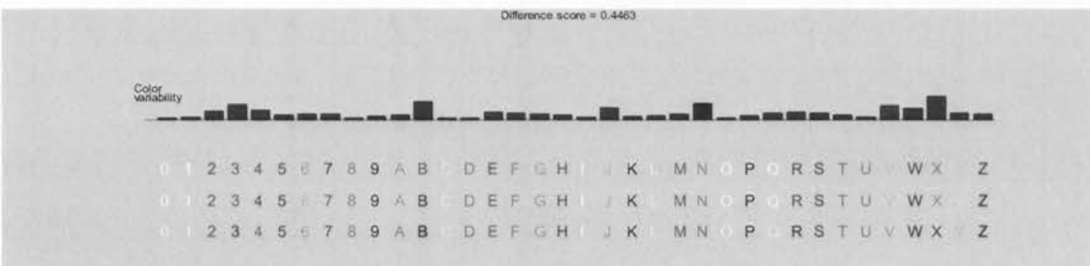

Figure 3-2. Screen display of GCAT results for participant JEN. Shown against a grey background due to white letters. Bar height indicates level of consistency. Tall bars indicate poor consistency.

Further evidence is also suggestive of an abstract letter unit hypothesis. The Simner et al., (2009) study of child synesthetes reports that even the 8 year olds who know their alphabet in full do not have a complete set of synesthetic associations. Instead colours are associated with graphemes over time, suggesting that some synesthetes' graphemes acquire colours earlier than others. In normal development, the first period in childhood where colours and forms are able to be bound in visual long term memory is approximately five years of age (Simmering, Johnson, Patterson, & Spencer, 2009). The ability to bind colours and form consistently is a minimum requirement for the existence of durable and consistent grapheme-colour associations. This suggests that there is a lower bound age for the condition and one which is consistent with the findings of Simner et al., (2009) above.

In short two possibilities for the binding of colour to grapheme orthography are suggested. The first is that colour is bound to sub-features of graphemes, and the alternative is that colour is bound to the abstract representation of the whole letter unit. These alternatives can be tested by examining the proportion of colour matching between synesthetes and controls for easily confusable pairs of upper or lowercase letters (Blair & Ryckman, 1969; Thorson, 1976) and also for our own list of orthographically similar grapheme pairings including numbers.

Having established in Chapter 2 that the internal consistency paradigm gives similar data and results to the retest consistency paradigm, we can confidently begin to assess these issues.

3.2. Aim and hypothesis

The purpose of our data analysis is to investigate observed patterns of colour matching in grapheme-colour synesthesia to elaborate on the role of learning and development.

The following analyses aim to:

1) Test for the manifestation of gender biased colours in the first letter initials of synesthetes and test whether these occur at a higher rate than those in the control group.

2) Examine the question of whether synesthetes or controls make more colour matches in their grapheme-colour selections and, if so, how colours are matched. To address these questions we look at the RGB values of our data and assess each letter pair for an exact colour match.

3) Test the strategic allocation of colour based on ordinal position or sequential position. Do graphemes which share the same position in a sequence also share the same colour? (A1, B2, C3 or AB, BC, CD etc)

4) Test whether upper or lowercase letter pairs that share their basic visual features - i.e. are easily confusable - are more likely to share their colours.

5) Test the strategic allocation of colour based on overall similarity of orthographic form including numbers and letter pairs. In order to undertake this analysis we create

a new matrix of grapheme pairs which include number-letter pairs. Some of the pairs in this matrix also appear in the 'easily confusable' matrices we used above. For example, Blair & Ryckman (1969) found that rotated capitals were easily confusable but since these are also orthographically similar they appear in this matrix.

6) Examine whether orthographically similar grapheme triplets (2,5,S) and quadruplets (3,E,M,W) share their colouring more often in synesthetes than controls.

3.3. Method

The data for this analysis was derived from the data provided by the participants in the GCAT in Experiment 1a. In Experiment 1a, we had a grapheme-colour synesthesia group of 29 and a control group of 107 participants. For the purpose of this analysis we excluded our gendered colour number synesthete, who did not have colour associations for letters.

We wrote a Matlab program for each of the 'grapheme pair – colour pair' tests we examined. Each program took the RGB values selected by the participant for the first presentation of each GCAT grapheme and used it as the item for analysis. Since we established the GCAT recommended cut off score of 1.12[11] (established as the total RGB differences across 3 rows of letters) we use this score, divided by three, as the criterion to determine a colour match. RGB differences between the pairs which derived a value less than 0.37 were defined as a match.

To assess the proposition that the extraction of early visual features is important in eliciting synesthesia, we searched the literature for any reference to a table of systematic letter pairing - such as would be achieved by similar visual construction (line terminations, horizontals, curvature). Apart from finding evidence that the lower case letters of b, d, p, q have been seen to be easily confusable by children - likely because identity is processed before orientation (Corballis, Zbrodoff, Shetzer, & Butler, 1978; Schendan & Lucia, 2009) - the only usable investigations of early reading which contained tables of confusability for letter pairs were by Thorson (1976) for uppercase and by Blair & Ryckman (1969) for lowercase letters. Neither table included numbers. These matrices were used to create the analysis of early visual feature extraction. Thorson (1976) defined confusability for uppercase letters as letters which share three or more distinctive visual features. Blair & Ryckman (1969) rated ease of confusability

[11] This is the actual value not the value which corresponds to the 0.1 increment. See section 2.3.1.3.4

by the number of errors children made in a discrimination task. We create the uppercase matrix using the whole published matrix of Thorson (1976) and the lowercase matrix on the basis of letter pairs in which 2 or more errors were reported in the Blair & Ryckman (1969) study.

We then tested for differences in the mean number of colour matching pairs between grapheme-colour synesthetes and controls as well as looked at the proportion of matches which occur in these confusability matrices against the proportion of possible matches in the remaining data set. If synesthetic colours are bound to physical form early in the visual feature integration process (i.e. before their categorical meaning is created) we would see graphemes which are easily confusable sharing their colours. Importantly we might also see these at a higher rate than pairs formed in the remaining data set.

For this and the remaining tests we include the use of 'no colour' as a match pair if it is made by the participant for both graphemes since this was often used for clear or transparent. We include it also because we wish to know whether 'no colour' matches have shape similarity in common. We note that clear/transparent is not an actual colour but we consider it to be a synesthetic association in its own right and as such should not be excluded from this analysis.

3.4. Results

1) Gender bias in colour allocations

Of the 25 female grapheme to colour synesthetes 7 (28%) have pink as the colour for the first letter of their first name. Pink is not a popular choice as a concurrent, it was only chosen 5% of the time in the GCAT by both synesthetes and controls. This figure is also higher than the chance level that would be predicted (9%). Recalling the confidence intervals we derived for the analysis in Chapter 2, any frequency of pink over 11% for controls and 18% for synesthetes is significantly large. In the control sample of females (N = 57), pink was matched with the subject's initial first name letter 6 times (10.5%), which is not significant, though indicates a trend. These associations might be derived by the groups in similar ways in childhood, with the association being much more enduring or memorable over time for synesthetes. (Chi-square (1) = 3.98, $p < 0.05$).

For males, the trend would have to reach 44% for blue for both groups. We had a much smaller sample of male participants with grapheme-colour synesthesia, all under 25 years. Of these 75% have blue as the colour for the first letter of their first name. In the control sample 20 of 51 (39%) males chose blue which did not reach significance, nor do we reach a trend for males to have blue initials (Chi-square (1) = 1.95, $p > 0.05$) over other colours. Assessment with a larger sample size of male synesthetes is needed to confirm the results for males.

With regard to numbers, seven female synesthetes but only two female non synesthete participants chose pink for the numbers 5 or 6. This is a significant difference (Chi-Square (1) = 9.32, $p < 0.05$), though one which may not survive correction for multiple comparisons. Two male synesthetes chose blue for 5 or 6 but given the small number of male participants we are cautious about how this observation contributes to any finding and would be interested to see if it is borne out in larger sample sizes. The number of gender related colours for the numbers 5 and 6 is a curious observation. Simner et al., (2009) have previously shown that grapheme-colour associations develop over time in childhood. If synesthetic associations start to develop at the age of 5 or 6 this might manifest in age and gender related colour associations. A related finding is that for lexical gustatory synesthetes the induced tastes are often childhood foods (Ward & Simner, 2003).

2) colour matching of grapheme pairs

First we developed a set of grapheme pairs to represent the full set of all possible pair combinations of graphemes (N = 630). We examined the most popular (top 20 of 630 possible) colour matching pairs for both groups.

In Table 3-1, we show the matches grapheme pairs for each group which are made by more than 20% of the group sample. We can clearly see a predominance of colour matches based on grapheme orthographic similarity (0O, A4, 5S, 8B, UV, VX); in the synesthete group and colour matches based on sequential patterns in the control group (1-2, 7-8). Synesthetes prefer to match colours based on grapheme form similarity, for example A with 4, where controls prefer a colour match based on ordinal position for example, A with 1, though both groups have exemplars of both types of strategies, 2 and 5 for controls for example and the ordinal (or phonetic) trend of 3 and C for synesthetes.

The strong sequential based colour matching strategy for controls would be expected given the large number of participants who did not utilise a varied strategy to do the test, preferring to have large numbers of selections in blue or green. We also acknowledge that the test instructions used in the Simner et al., (2009) study where children were assessed with a two iteration colour association test may have been helpful in our test administration. Simner et al., (2009) instructed the children to avoid repeatedly selecting the same colour which we did not do. Notwithstanding this synesthetes (N = 28, M = 66.86, S.E. = 5.25) make no more matches overall than controls (N = 107, M = 74.62, S.E. = 2.97), $t(133) = -1.212$, $p = 0.228$, nor do synesthetes (N = 28, M = 34.96, S.E. = 3.58), make more letter to letter colour matches than controls (N = 107, M = 38.06, S.E. = 1.69), $t(133) = -0.821$, $p = 0.413$). This suggests that neither of the groups has a greater propensity for making colour matches in the test, even though the way they make the matches appears to be different.

Grapheme Pair		**% of synesthetes making the match**	**Grapheme Pair**		**% of Controls making the match**
0	O	61%	1	2	21%
1	I	32%	1	A	22%
3	C	29%	2	5	23%
4	A	29%	4	5	22%
5	S	32%	4	6	21%
7	E	29%	5	6	22%
7	L	29%	7	8	22%
8	B	36%	9	X	22%
9	B	29%	E	G	21%
9	N	29%	H	N	21%
9	P	29%	M	N	21%
D	T	32%	P	Q	21%
H	Y	29%	X	Z	30%
L	Y	32%			
T	Z	29%			
U	V	39%			
V	X	29%			
X	Z	39%			

Table 3-1. Most popular colour matching pairs for synesthetes and controls

3) Sequential matching

3a) Ordinal Matches

We tested whether the number of ordinal matches (A-1, B-2, C-3) would be different between the groups. We used numbers 1 to 9 and letters A – I. Synesthetes (N = 28, M = 0.643, S.E. = 0.16) and controls (N = 107, M = 0.56, S.E. = 0.07), do not differ in the number of ordinal matches made $t(133) = 0.53$, $p = 0.597$. We also did not find an effect when we reduced the sample to the first three numbers and letters.

4b) Sequential matches

We tested whether the observed pattern of sequential matches for controls would be different between the groups. We paired 1 with 2, 2 with 3, 3 with 4, A with B, B with C, C with D etc.. Synesthetes (N = 28, M = 3.57, S.E. = 0.46) make significantly fewer sequential matches than controls (N = 107, M = 4.95, S.E. = 0.29), $t(133) = -2.272$, $p = 0.025$. This is not surprising because this result could be driven by the large proportion of control participants selecting similar colours for all graphemes. This is also supported by our finding that controls have colour selections for graphemes in alphabetical order based on how easy the colours are to generate.

4) Early Visual Feature extraction

4a) Lowercase form confusability

Twenty-five lowercase easily confusable letter pairs based on the work of Thorson (1976) (Appendix D) were examined for colour matches. Synesthetes (N = 28, M = 2.50, S.E. = 0.31) do not match colours for easily confusable lowercase pairs any more or less frequently than controls (N = 107, M = 3.22, S.E. = 0.205), $t(133) = -1.685$, $p = 0.094$. We also derived proportions of matches both for lowercase confusable colour parings and for matches from the remaining six hundred and five possible grapheme – grapheme matches. A repeated measures ANOVA between the proportion of coloured pairs in this matrix and the proportion of coloured pairs in the remainder of the set found no main effects. ($F(133) = 0.102$, $p = 0.750$). We conclude that neither synesthetes nor controls match colours to easily confusable lowercase letters systematically. The rotated lowercase letters b, d, p, q were not often found to be similarly coloured by either group.

4b) Uppercase form confusability

Seventy uppercase easily confusable letter pairs based on the work of Blair & Ryckman, (1969) (Appendix E) were examined for colour matches. Synesthetes (N = 28, M = 8.71, S.E. = 1.08) do not pair easily confusable uppercase letters any more or less frequently than controls (N = 107, M = 8.38, S.E. = 0.44), $t(133) = 0.324$, $p = 0.746$. We derived proportions of matches, both for uppercase confusability colour parings and for matches between the remaining five hundred and sixty possible grapheme – grapheme matches. A repeated measures ANOVA between the proportion of coloured pairs in this matrix and the proportion of coloured pairs in the remainder of the set and found a marginal main effect for group ($F(1,133) = 3.818$, $p = 0.053$). This group difference appears to be driven by synesthetes having proportionally fewer colour matches for easily confusable uppercase graphemes (N = 28, M = 0.11, S.E. =

0.008) than the controls (N = 107, M = 0.12, S.E. = 0.005). The interaction however, was not significant ($F(1,133) = 2.826$, $p = 0.095$).

5) Grapheme identified matching - Colour matches based on graphemic orthographic similarity

Since none of the matrices we found in the literature considered numbers as confusable with letters we developed a matrix of grapheme pairs that we would consider to be similar in ordinary everyday use as well as those which would be similar in the early learning of writing (such as in BLOCK writing or the rotation of uppercase and lowercase letters). We developed a set of seventy pairs, of which thirty-eight were number - letter pairings. These appear in Appendix F.

On the whole synesthetes (N = 28, M = 11.11, S.E. = 1.04) match the same colours to orthographically similar grapheme forms more often than controls (N = 107, M = 8.86, S.E. = 0.45), $t(133) = 2.19$, $p = 0.031$.

For the seventy orthographically similar grapheme pairs we ran chi-squares using Fisher's exact tests to determine which colour matched pairs were made specifically more often by synesthetes than controls. Uncorrected significant chi-squares for several pair matches can be seen in Table 3-2.

Pair	r	df	P FE (two sided)	P FE (one sided)
0O	19.575	1	.000	.000
4A	9.453	1	.005	.005
1I	7.40	1	.015	.011
UV	5.91	1	.021	.017
9b	6.14	1	.028	.019
0Q	4.91	1	.049	.034
Pq**	4.53	1	.045	.023
6q**	4.19	1	.045	.029
7V	4.49	1	.05	.05
OQ	4.16	1	.059	.048

Table 3-2. Chi squares for colour matches based on orthographic similarity for synesthetes and controls
** chi squares show this trend in favour of controls

We then divided the matrix into two types of pairs. Those grapheme pairs where the orthographic similarity was between a letter and a number (different category) and those pairs where both graphemes were letters together or numbers together (same category)[12].

[12] Of the 32 same category pairs, only 3 are number - number pairs. (2 5, 6 9, 3 8)

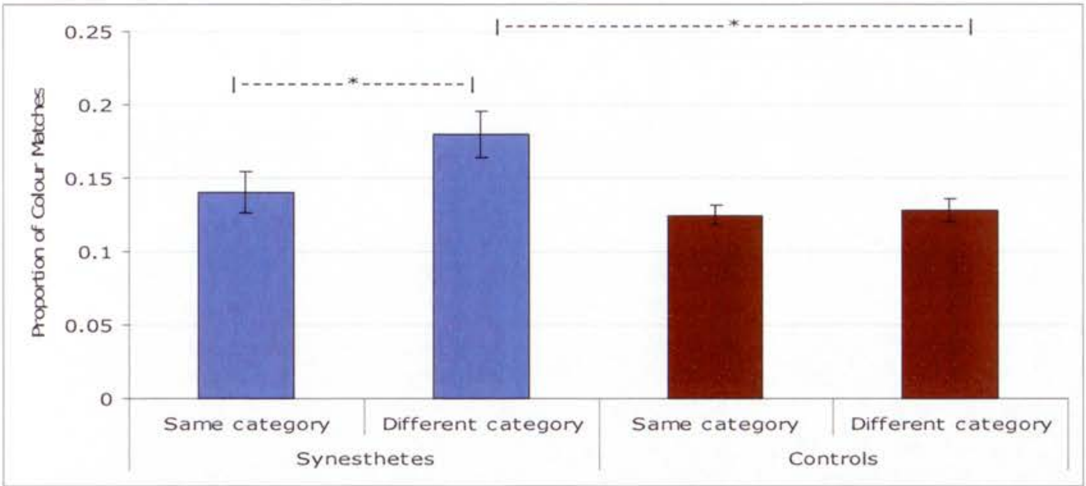

Figure 3-3. Proportion of matching colours for same category and different category grapheme pairs for synesthetes and controls. Error bars represent one S.E. of the mean. * indicates post hoc analysis shows a significant difference

A repeated measures ANOVA found both a significant main effect for pair type, ($F(1,133) = 6.38$, $p = 0.013$) and an interaction with group ($F(1,133) = 4.995$, $p = 0.027$). Post hoc analysis showed no significant difference between the groups for the proportion of same category pairs (contrast estimate = 0.015, $p = 0.370$) but a significant difference between the groups for different category pairs (contrast estimate = 0.053, $p = 0.004$). Synesthetes colour match different category pairs more often than controls and more often than they match same category pairs which share similar grapheme form.

We also considered the effect that matching colours on the basis of shape might have on the overall GCAT score. The total number of colour matches based on grapheme pair orthographic similarity was negatively related to the GCAT total colour match consistency score for synesthetes (N = 28, $r = -0.490$, $p = 0.008$). This however, was not true for controls (N = 107, $r = -0.039$, $p = 0.689$). The more colour matches a synesthete had in their data set, the lower the level of total variability. We considered that this might be a consequence of the use of fewer colours. We calculated the number of Berlin and Kay (1969) basic colour categories unused by each participant and found it was not significantly (though marginally) correlated with the total number of shape matches (N = 28, $r = 0.347$, $p = 0.071$). Therefore the lower GCAT score for synesthetes who had a large number of orthographically similar pairs was not simply a result of a restricted colour choice strategy.

6) Triplet and quadruplet colour matches

So far we had only considered pairs of graphemes, however, it was possible to create triplets and quadruplets of orthographically similar graphemes – particularly those which were the same when rotated. Several synesthetes had three shape colour matches and two synesthetes had at least one quadruplet. These were not seen in the control data, (except as a result of the control participant selecting the same colour over and over for more than 50% of the total grapheme set). One notable quadruplet was produced by JK, a projector synesthete; 3EMW in emerald green.

In the synesthete data set there were two frequently occurring triplet colour matches. 7 of 28 (25%) synesthetes matched 0, O, and Q - three of which were in white. 3 of 28 synesthetes (10.71%) matched 2, 5, and S.

3.5. General Discussion

The GCAT test originally provided a simple method by which to examine the patterns of colour allocation to graphemes. In this chapter we extended the use of the GCAT data to consider other patterns of grapheme-colour association with a particular focus on those grapheme pairs that are consistently matched for colour and whether these differed between the groups.

The first finding was that synesthetes appeared to have gender specific colours for the initial of their first name to a greater extent than control subjects. This finding needs further interrogation in a larger data set of synesthetes. A cross cultural analysis would be interesting also, as would an analysis of different generational age categories as different gender and colour associations were in place before World War 2. Prior to the second world war pink was associated with males - pink being a weaker version of red. Light blue was associated with females. Colour letter sets before this time, such as those found by Day (2005), may reveal interesting information. It may also be interesting to see whether this pattern holds in some cultures who are not heavily influenced by western consumerism, or who have different cultural norms for gender and colour. If grapheme-colour associations reflect personally relevant associations which occur when the associations are being made, and visual long term memory cannot bind colour and form until the age of approximately 5 years old - a lower limit for the development of grapheme-colour synesthesia could be tested.

The second finding was that synesthetes do not make any more or less colour matches between grapheme pairs than controls overall. This means that any bias found in the data was not due to an overall propensity for colour matching between the groups. Investigations also revealed that there was no trend for colour matching between ordinally matched grapheme pairs for synesthetes but controls were more likely to match colour to graphemes based on sequence. This is likely the result of many controls selecting the same colour repeatedly.

The most interesting results are those which are related to the colour matching of orthographically similar graphemes. Three results are of interest:

1. Synesthetes make more colour matches for orthographically similar grapheme pairs than controls.
2. These are significantly greater for different category pairs than same category pairs.
3. Synesthetes colour matching extends to grapheme triplets and quadruplets and is evident in rotated capital letters.

Hammer, Diesendruck, Weinshall, & Hochstein, (2009) argue that in learning processes, young children are more likely to rely on unsupervised category learning strategies affected by bottom up factors, such as global similarity judgement. This may be a simple account for the colour match based on orthographic similarity, and it would not be inconsistent with the proposition that they are learned over time. However, it does not explain why we find that synesthetes have a stronger propensity to colour match orthographically similar different category pairs over same category pairs. When we assessed this aspect of colour matching we found that the proportion of different category pairs exceeded the proportion of same category pairs considerably. This was most obvious when the graphemes were capital letters. A quick examination of the common matches noted earlier by synesthetes bears this out. 1:I, 2:5:S, 3:E, 4:A, 6:9:P B:8.

Each grapheme might not acquire its colour by a unique pairing event. It is possible that some graphemes have primary colour associations and others are translations or migrations of them. This would mean that a child synesthete's grapheme-colour associations could develop over time by the same (currently unknown) mechanisms that are seen in the translations of synesthetic colour between alphabets in language learning of adult synesthetes. This suggestion would be consistent with the observation that grapheme-colour associations are transferred across alphabets of different languages on the basis of the grapheme's orthographic or phonetic similarity.

Mills et al., (2002) report a case of a multilingual synesthete MLS who has synesthesia for several languages and alphabets including English (native) and Cyrillic (learned as a teenager). MLS's migration from one alphabet to another is systematic. The researchers report that the colours of her Cyrillic alphabet were matched to those in her English alphabet, in three roughly equal proportions. First, on the basis that the letters use the same sound, second, that the letters have the same shape and finally where both letter shape and sound combined are the same. Those that were based on sound were more likely to be those where there were no English letters which were similar in appearance (Mills et al., 2002). Barnett et al., (2008) examined multilingual and trilingual synesthetes in Ireland using word stimuli and found that the colour of a synesthetic association is more likely predicted from the visual properties of the words used. They conclude that shared auditory form is unlikely to be a main contributing factor in translation across languages. They also found that the later a language is learned the more likely visual properties drive the colour translation. Consistent with the finding by Simner (2009) is the work of Scherf, Behrmann, Kimchi & Luna (2009) who reported that the processes required to gather shape information – particularly that used for perceptual grouping - develop late into adolescence. It is possible therefore that even though development of the synesthetic perception may commence in early childhood it may continue to form quite late in adolescence. Colour matching based on orthographic similarity might be likely to occur in later developmental stages of synesthesia. This is largely inconsistent with the proposal of Spector & Maurer, (2008) who assert that these connections and associations are likely to be formed in infancy.

Translated synesthetic associations also appear to be as valid as the originals which would make determining which associations were primary and which were secondary difficult to ascertain. Mroczko, Metzinger, Singer, & Nikolic (2009) have shown Stroop interference for new synesthetic associations that have occurred as a result of transfer to a new alphabet (Glagolitsa) after a 10 minute learning (by writing) exercise. Therefore transfer may occur quite automatically. Transfer from the primary association would be difficult to deduce in adult populations and is a good reason why longitudinal developmental studies of synesthesia are needed. Evidence of colour transfer could be found, however, by examining the grapheme-colour sets of synesthetes and analysing the patterns for colour matching between graphemes. The research question would simply be: do the grapheme-colour sets of synesthetes show evidence of colour transfer based on orthographic or phonetic similarity? Phonetic attributes of letters and numbers are too similar, and too many graphemes share the same phonology; 3, b, c, d, e, g, p, t, v, z, for example. This makes an analysis with our small data set difficult: Therefore we focussed our analysis on the physical attributes of a grapheme: its orthography. Larger data sets are needed for such analyses.

Perea, Dunabeitia, Pollatsek, & Carreiras (2009) assert that different cortical mechanisms are involved in processing numbers and letters. It may be likely that colour matching strategy is based on a categorical evaluation between letters and numbers and that this occurs late in development, once the difference between letters and numbers is understood. Colour matching to graphemes might be explicit, not implicit and the subject of significant influences in learning.

There are limitations to our analysis. First we have not considered the intermediate stage in letter processing. The work of Petit et al., (2006) argues for a case specific processing stage between the grapheme form extraction and the formation of letter identities that are case independent. Such case specific processing strategies do occur in development and in particular in letter learning where lowercase letter learning lags behind uppercase letter learning. Some additional evidence that this stage is separable from the others comes from the grapheme to colour associations of synesthetes. One case example was provided by Ramachandran & Hubbard, (2003) whose synesthete participant 'E' has several case specific colour associations. EL in our study also has a few colour changes with case changes. She reports a capital R which is different colour to her lowercase letter. However, it is rare that any letter is a different colour for upper and lowercase or changes in font.

There is further evidence that shape colour conjunctions are based on structural descriptions that are case dependent (Walker & Hinkley, 2003). Recognition memory for shape colour conjunctions was examined in college student samples. By changing both case and font, Walker & Hinkley (2003) determined that font changes did not impair recognition memory for shape colour conjunctions but changes to case did. They concluded that colour was linked to the structural, not pictorial representation of the letter. Whether or not synesthetic colours are co-joined to structural or conceptual representations is a matter worthy of further investigation.

It is clear that a grapheme's orthographic form is not the only mechanism by which a colour association can transfer to another grapheme. In addition to the sound based translations mentioned above, colour associations can be influenced by the learning of the basic ordinal sequences ABC and 123 – though when examined they are not significantly present in group level analysis. To illustrate this point we provide a case example from our participant pool (BR). BR is a 22 year-old male synesthete who, at the time of initial testing, was fully aware of his numbers for colours but quite unsure of his associations for letters. During the GCAT he attempted on several of the trials to select colours for letters but did not select colours on all three occasions. After 6 months BR returned to the lab announcing quite unexpectedly that that he had "worked out" what these other associations were, having "never given them much thought before the first testing session." BR's letter colour associations line up specifically with the number colour associations (A is the same colour as 1, B with 2, C with 3, except for I with 9, which is white, so the colour for 9 is matched with J). Whether these associations were always there but latent or whether these translations occurred in the interval between testing is unclear (roughly half of the associations attempted for letters matched from the first testing session to the second). BR reported that he believed that the letter colours were based on guitar music chords which he was in the process of learning and practicing regularly. Thus there appears in synesthesia the possibility of colour matching or transfer involving higher-order or categorical principles (such as ordinal sequence) rather than lower-order principles involving form or sound similarity. Any explanation of why graphemes systematically share their colours will need to account for these strategies as well as the similarity between grapheme orthography.

In summary, we have examined the data that the GCAT has provided and extended its use to examine strategic colour allocation patterns as well as the question of how graphemes come to have the same colour. New principles underlying the allocation of colour to graphemes have been proposed. In particular we propose that orthographically similar graphemes are likely to share their colour if they are different category pairs. These pairs are most likely to occur because numbers and letters are categorically distinct and are transferred by the similar mechanisms as those in the transfer of colour to new alphabets. More importantly, it seems unlikely that colour is bound to early visual features of letters (or at least the combination of those that makes them easily confusable). Colour is most likely bound to the abstract representation of the grapheme of which form is only one component.

In short, this chapter has asked and answered the following broad question: With thirty-six graphemes and eleven basic colour categories, some graphemes must share the colour categories available for assignment to them – does this occur in a systematic way? The answer is yes.

4. WHAT DOES THE SYNESTHETIC STROOP EFFECT REALLY MEASURE?

4.1. Introduction

In this chapter attention is turned to the synesthetic Stroop paradigm. Stroop paradigms are response time tasks in which information in one dimension interferes with processing in another dimension. For example, reading the names of coloured words interferes with naming the ink colour in which they are printed. In synesthesia research, a Stroop paradigm manipulates the congruency of the synesthetic associations of participants.

The Stroop effect (Stroop, 1935)[13], is generally thought of as the "gold standard" to measure automatic processing (Melara & Algom, 2003) and to reflect processes which are immune from deliberate cognitive control. This paradigm is very appealing for synesthesia researchers who wish to test that synesthesia is the result of fast acting automatic processes (Spruyt, Koch, Vandromme, Hermans, & Eelen, 2009) rather than deliberate contrivances or learned and remembered correspondences. The Stroop paradigm therefore has been adapted for a variety of purposes in the field.

Wollen & Ruggiero (1983) were the original researchers to use a Stroop paradigm to assess synesthesia. First, they asked whether there was any cognitive process mediating synesthesia and second whether a synesthetic concurrent could be ignored. The authors tested these hypotheses by assessing their single participant's response times when naming ink colours of coloured circles and naming the associated synesthetic colours when viewing black letters. There was no difference in the mean response times between naming coloured circles and naming associated synesthetic colours. Hence, they concluded that synesthesia is "instant" rather than mediated by other cognitive processes. This finding was replicated in another study where it was found that naming times for the colours of congruently coloured numbers was no different to the naming time for colours of circles or the synesthetic concurrent of black digits, but that all three were significantly faster than mismatched or incongruently coloured digits (Mills, Boteler, & Oliver, 1999). The authors concluded that synesthesia was automatic, involuntary and unidirectional. In yet another single

[13] See Macleod (1991) for a review.

case study with a digit synesthete, negative priming increased Stroop interference (Odgaard, Flowers, & Bradman, 1999).

Smilek et al., (2001) were the first to assert that Stroop interference is a marker of genuine synesthesia. They asserted this on the basis that the Stroop interference clearly distinguished between two identical twins, only one of whom experiences synesthesia. Going back as far as 1983, at least 30 studies examining synesthesia have used Stroop like paradigms. The majority have used single case studies, and there are few group level comparisons.

Stroop paradigms to examine group differences with synesthetes were first used by Mattingley et al., (2001). They found using the same colour digit stimuli for both synesthetes and controls, that interference was prevalent for the synesthetes when required to name the colour of incongruently coloured digits but not for controls. They extended the use of Stroop to examine the issue of automaticity and conscious reporting by masking the inducing stimuli and found that synesthetic Stroop interference was eliminated when the inducer was unavailable. A further experiment examined group differences in the effect of attention on a letter priming task. A congruity effect was found for synesthetes that was modulated by the level of attentional load. This was not found for controls.

There is one important assertion in the literature related to the synesthetic Stroop paradigm to which consideration is given in this chapter. That is, the synesthetic Stroop effect is an "objective cognitive marker" (Mattingley et al., 2001) and an indicator of the automaticity (Mattingley et al., 2006) and genuineness of synesthesia (Cytowic & Eagleman, 2009; Smilek et al., 2001). There are many studies using synesthetic Stroop paradigms in which the experimental manipulation clearly differentiates between synesthetes and controls. If synesthetic Stroop effects are objective markers of the condition and therefore unique to synesthesia, then they should not be seen in control subjects under any circumstances. Evidence is mounting however, that the Stroop paradigm may not be the objective marker it was originally thought to be. Recent publications have reported that a synesthetic Stroop effect can be elicited in controls. In particular, Meier & Rothen (2009) and Elias, Saucier, Hardie, & Sarty (2003) show that the synesthetic Stroop response can be elicited in controls after training in synesthetic associations, and Cohen Kadosh, Henik, Catena, Walsh, & Fuentes, (2009) provide evidence that controls can demonstrate a synesthetic Stroop effects after post-hypnotic suggestion.

What is primarily at issue in our investigation of the synesthetic Stroop effect is whether this effect is actually unique to synesthetes. Aside from the evidence presented above (that the effect can be induced by training and post hypnotic suggestion), there is also a fundamental methodological problem with the synesthetic Stroop paradigm as it has been used to date. This problem rests in the fact that control participants are matched to synesthetes and tested using the synesthetes' grapheme to colour associations as the stimuli, not their own. This is based on a false assumption that control subjects do not have any associations to examine. While this controls for basic stimulus differences, it does not control for the ability to associate graphemes to colours consistently – something controls can do to a limited extent and which was demonstrated in the GCAT in Chapter 2. In previous experiments it is not surprising that a lack of congruity effect is found for controls because there is no reason to expect that a synesthete's stimuli has any meaning whatsoever for the control participant. To date no experiment has been conducted in which controls are administered stimulus ensembles comprised of their own unique grapheme-colour associations. Since synesthete and control subjects can complete a grapheme to colour TOG, deriving a unique stimulus ensemble for each control subject, is now as straightforward as it is for synesthetes. This is another advantage derived from using the Synesthesia Battery.

Two synesthetic Stroop paradigms are reported in this chapter. In the first, participants are asked to name the screen colour of a presented inducer. In the second, participants are asked to name the colour they associate with the presented inducer. Each experiment type has a strong history of use in the synesthesia literature. However the latter has never been conducted with a control group. This is due to previous researchers claiming that control subjects cannot be evaluated on this paradigm because they have no synesthetic associations to report in the experiment (Lupianez & Callejas, 2006). A further claim therefore follows from researchers, that this Stroop interference in this test proves the genuineness of synesthesia because it is an effect that cannot be observed in non-synesthetic individuals. The use of a unique stimulus ensemble for control subjects makes a comparison and evaluation of this synesthetic Stroop paradigm now possible and the claim falsifiable.

If it can be shown that the synesthetic Stroop effect can be reliably elicited by non-synesthetic individuals when each participant is administered a unique and relevant stimulus ensemble, then this raises the question of what the synesthetic Stroop effect actually measures. Is it a measure of synesthetic perception or the strength of latent, or learned grapheme-colour associations?

4.2. Rationale, Limitations and Opportunities of the Experimental Design

There are many different structural designs used in Stroop experiments. Invariably when a researcher selects one design it forces the exclusion of the other. The choice is influential in the interpretation of results.

In the screen colour naming tasks of Experiment 5 and 7b, we adopted the more traditional Stroop design. A neutral baseline condition was utilised and the design structure presents the experimental conditions an equal number of times. A neutral condition is not utilised in the associated colour naming tasks of Experiment 6 or 7c due to the task manipulation.

The Stroop effect is considered to be evident if the mean response time to trials which are congruent are faster than the trials which are incongruent. However, Stroop paradigms are utilised both with and without neutral (baseline) conditions. Where neutral measures are used, facilitation effects (congruent minus neutral) and interference effects (incongruent minus neutral) can be made. In experiments which do not use a baseline condition, the use of the term interference becomes synonymous with the incongruent condition and facilitation with the congruent condition. This fact makes comparisons between studies difficult and confusing as the terms take different measurements and assume different underlying causes.

In this thesis we consider that there are three main effects that can be derived in a Stroop paradigm when a neutral condition is included; Interference, Facilitation and Congruity. For the purposes of our study these effects are:

Congruity: A congruity effect is defined as the difference between congruent and incongruent conditions and has usually been used when no neutral condition is present. Congruity is therefore defined as: median RT Incongruent minus median RT congruent.

Interference: An interference effect is defined as the difference between incongruent and neutral conditions and has usually been used when a neutral condition is present. Interference is therefore defined as median RT incongruent minus median RT neutral.

Facilitation: A traditional facilitation effect is defined as the difference between congruent and neutral conditions and has been used when a neutral condition is present. Facilitation is therefore defined as median RT congruent minus median RT neutral. Facilitation for our purpose also includes "reverse facilitation" where congruent trials are slower than neutral trials (Cohen Kadosh, Cohen Kadosh, Henik, & Linden, 2008).

Of the group level analyses in the synesthetic Stroop literature, few include baseline or neutral conditions and where these are used the relationship of the baseline to the manipulation of congruity is not reported[14]. The majority of papers report congruity effects. They compare congruent vs. incongruent conditions across some other dimension such as numerosity or context (Gebuis, Nijboer, & van der Smagt, 2009; Myles et al., 2003) or they compare group by congruity (Johnson, Jepma, & de Jong, 2007). However, without a baseline condition changes across an experiment and interactions between the dimensions in the experiment cannot be fully interrogated. There are also several confounds in the Stroop literature that should be teased apart. First, congruity is not equivalent to interference despite a bias in the interpretation of published Stroop results to that effect (MacLeod, 1991). Congruity effects may involve some facilitation. Since measures of facilitation and interference from baseline are often not made, many researchers interpret their findings in terms of the cost of processing incongruent over congruent trials rather than the advantage congruency may give. It is important to test this by using a neutral or baseline condition.

Limitations of the design: Choice of traditional structure design may have an influence on effect size.

It was mentioned earlier that there are a number of ways to design and structure a Stroop experiment. Each has benefits and costs. For the most part, experiments contrast congruent and incongruent conditions but a baseline condition can also be used. If these are delivered separately they are termed blocked designs and if these conditions are administered together they are termed intermixed. An intermixed design is used in the experiments reported in this chapter.

In the case of choosing a traditional structure, benefits accrue to researchers because the results of the experiment can be compared with a broad range of literature and can be interpreted and used by researchers in other fields. To date, there are few

[14] for an exception see Cohen Kadosh (2007).

group level studies of the synesthetic Stroop paradigm and none have utilised a traditional structure. According to the tectonic theory of Stroop effects, (Melara & Algom, 2003) however, there is also a cost to traditional structures because the context of the stimulus presentation fundamentally affects the level and type of facilitation and interference effects seen in the experiment. In particular, Sabri, Melara, & Algom (2001) argue that the covariate context (the level of correlation between congruent and incongruent items) has a significant influence on the effects seen in Stroop paradigms by determining the stimulus uncertainty and predictability (either within or between dimensions (colour/letter)).

Covariate context is explained as follows: Stimuli are said to have a perfect or 0 covariate context if the number of times each stimulus presented is equivalent. In synesthetic Stroop experiments this would mean that a red coloured A and a green coloured C (congruent) and a red coloured B and green coloured D (incongruent) would be presented an equal number of times. Red or green is not predictive of either letter nor is either letter predicative of red or of green. In a traditional Stroop experiment a red coloured A (congruent) is presented for each time a red coloured B, C, or D (which are now all incongruent) is presented. This is said to have a positive covariate context as the grapheme A becomes predictive of red. In short a positive covariate context (over 0) is "typical of the stimulus sets testing in the vast majority of recent Stroop studies" but is said to create "a correlation over trials between word and colour dimensions" (Melara & Algom, 2003).

In the experiments reported in this chapter a 0.25 covariate context was used. While there were an equal number of congruent, incongruent and neutral stimuli, the ratio of our congruent to incongruent targets was 4:1. For each differently coloured (incongruent) As, one congruently coloured A was presented. Therefore in a screen colour naming task, the distracter grapheme is predictive of colour (for example there are 4 red As and one of each blue, green, yellow and pink As). The important issue is that according to the theory, when anything but a 0.0 covariate context is used, grapheme distracters come to be predictive of colour (the tilde symbol is not). Thus "the conditional probability of a word (*in this case a grapheme*) matching its colour is higher than that for any other combination" ... "thereby lowering the dimensional uncertainty of any congruent stimulus" (Melara & Algom, 2003). This assists participants to expect matching values while performing the task, which can "culminate in enhanced performance on congruent trials relative to incongruent trials" therefore creating the overall Stroop effect. This is an important issue for our experiment because it makes it possible that any Stroop effects (congruity, facilitation and interference) that are found might derive mainly from the covariance context utilised and not from the participants grapheme-colour associations. Including a neutral condition can assist in examining this effect.

Two possibilities present themselves for resolution of this issue. The first, is the simpler of the two. A post hoc analysis of the experimental data which examines whether any congruity effects that may be seen are cumulative, can address this question. The second possibility requires that a full comparison with the alternative covariance design be conducted. Since this is not the main hypothesis under investigation, and since this would also have required a separate study to be conducted, we have elected to do the former. Notably the latter suggestion may be a worthwhile investigation in its own right.

If the tectonic theory is correct, the following effects in our experiment would manifest. First, covariate context effects should not be evident at the beginning of the experiment. At commencement the participant has not yet learned that A for example is predictive of red whereas the participant would have learned this by the end of the experiment. Any effect at the commencement of the experiment should therefore be due to the experimental manipulation. Second, if tectonic theory is correct, the effects should be most evident by the end. A congruency effect at the end of the experiment would then be due to both the experimental manipulation and the covariance context. Finally the effects should accrue due to facilitation not to a loss of interference as the theory specifically states that the advantages should accrue to congruent trials.

Are synesthetic Stroop effects related to the strength or consistency of the synesthetic association?

All participants completed the GCAT and it is from the GCAT that we developed unique stimulus ensembles used in the synesthetic Stroop experiments. One of our synesthete participants (JK) reported projected synesthetic colours for geometric shapes as well as graphemes, but that the synesthesia for geometric shapes was weaker. This presented us with a unique opportunity to assess her claim that the strength of the synesthetic concurrent was different between the two inducer types. By comparing the Stroop effects evident in her data in each Stroop paradigm a simple measure of her self report could be made which would either support her claim or not. If support for this claim was found, it might assist in the interpretation of any stroop effects seen in the control sample.

One further method of exploration of the relationship between the strength of the association and stroop effects was also possible. If the colour match consistency scores in the GCAT reflect the consistency, certainty or strength of the association between the graphemes and colour, we can investigate whether this score is specifically correlated to any of the Stroop effect measures of congruity, interference or facilitation.

It is difficult however to form an a priori hypothesis about which of the effects would be most likely related because there is a great deal of debate as to whether the Stroop effects of facilitation and interference stem from one mechanism or if they are separate things. Chen (1996) and also Lindsay & Jacoby, (1994) argue that Stroop paradigms cannot dissociate facilitation and interference. However, MacLeod (1998) found that training associations over several days had little effect on facilitation but interference fell quickly and then stabilised, suggesting that training influences each aspect differently. Fuentes & Ortells (1993) found different effects for facilitation and interference under different conditions of para-foveal distance and Cohen Kadosh et al., (2008) and Cohen Kadosh et al., (2007) show that differences between facilitation and interference may be task dependent.

Current neuro-physiological evidence seems to argue in favour of separate mechanisms. Szucs & Soltesz (2007) argue that facilitation and interference occur at "multiple stages of perceptual and response processing". Facilitation effects in their study were seen at early perceptual stages as well as at response stages. Interference effects were only seen in their study at conflict monitoring and action selection, i.e. the response stage. Interference was also seen to be a response processing effect as evidenced by late peaks in ERP difference waves by Badzakova-Trajkov, Barnett, Waldie, & Kirk (2009).

If synesthetic Stroop effects are related to the GCAT score then it might be possible to develop a line of inquiry which can guide future investigations of the synesthetic Stroop effect. If the proposition that synesthetes and controls show similar Stroop effects because they both have the inherent ability to associate graphemes to colours, then we would expect that the GCAT scores will be related to the Stroop effects in some way. If facilitation and interference stem from different mechanisms then a relationship might only be seen for one or the other. If the synesthetic Stroop effect measures both facilitation and interference we would expect the GCAT score to be correlated with them both. If Szucs & Soltesz (2007) are correct that interference is a response processing effect then we might expect that the GCAT scores would be strongly correlated with interference only. Finally, if facilitation effects occur early in processing and the synesthetic stroop experiment elicits a perceptual experience then only synesthetes might exhibit a relationship between the GCAT score and facilitation. We therefore present one broad hypothesis for exploration; that the GCAT colour match consistency scores will be related to Stroop effects elicited in the experiments.

In summary, one point is worth reinforcing. Regardless of the structural (tectonic) design or the main experimental manipulation (using unique and relevant stimulus ensembles for each participant), if any Stroop effects are seen for the control group, the confidence researchers have in Stroop effects being diagnostic or unique to synesthetes is diminished. Further, the underlying causal nature of the Stroop effect seen in synesthesia will need further investigation.

4.3. Aims and Hypotheses

The main experimental proposition examined in this chapter, is that the Stroop congruity or interference effect seen in previous research is not a unique cognitive marker or measure of genuineness of synesthesia. It is likely due to the strength of a consistent or habitual association. That the effect has not been seen in control subjects before is due to a consistent and inappropriate application of control stimuli in previous experiments.

The predicted effects in the experiments to be reported here would be that control subjects would show synesthetic Stroop effects in both the colour naming and the associated colour naming experiments. With regard to facilitation and interference, the expectation is that synesthetes would show stronger levels of these effects. This could be due to two different causes which are not teased apart by this study. First they may result from synesthetes having perceptual (synesthetic) experiences of the graphemes in the experiment. Second, synesthetes may have stronger conceptual associations between graphemes and colour because they use and reinforce the grapheme-colour relationships in everyday life, such as to remember peoples' names and telephone numbers, which control participants do not.

With regard to the design choice, a post hoc analysis of the first and last 10 trials of each condition will be assessed to determine whether the tectonic theory effects that would be predicted manifest in the experiment. These effects would be an increase in facilitation from the outset to the conclusion of the experiment and an increase in any congruity effects.

Finally, Stroop effects will be related to the colour match consistency scores obtained in the GCAT.

In short, our aim is to discern whether improvements to the quality of the current synesthetic Stroop paradigm result in changes to the effects seen in previous studies. The design of the paradigm is modified in two ways. First by the inclusion of a neutral condition and second, by using stimulus ensembles for control participants derived from their GCAT performance.

4.4. Experiment 5 - Synesthetic Stroop Screen Colour Naming

4.4.1. Method

4.4.1.1. Participants

24 control participants and 20 grapheme to colour synesthetes volunteered for the screen colour naming (SCN) Stroop experiment.

Control participants were students of the Psychology department of the University of Sydney. Control participants that undertook the GCAT test in Experiment 2 were only selected for this experiment if they exhibited 5 different and consistently coloured graphemes. Four control participants were excluded due to technical issues with the equipment or a lack of attention to the task. Of the 20 control participants whose data were analysed, GCAT scores ranged from 0.70 to 2.67. (N = 20, M = 1.67, SD = 0.52). None reported grapheme-colour synesthesia or any other forms of synesthesia.

All synesthetes scored below 1.12 in the GCAT and their scores ranged from 0.39 to 1.12. (N = 20, M = 0.64, SD = 0.21).

Participants gave informed written consent and the study was approved by the Human Research Ethics Committee of the University of Sydney. Participants volunteered, were reimbursed $20 per hour of testing or received course credit for the time involved. Participants were naive to the manipulation of the experiment.

4.4.1.2. Stimuli and Equipment

The stimuli were graphemes: letters, numbers and the tilde (~) symbol. Five different grapheme selections and the tilde symbol were used for each participant. A single stimulus was used for the neutral condition because it is difficult to find non inducing graphemes that are non-inducers for all synesthetes.

Graphemes and their matching colours were drawn from the colour associations selected by each participant using the GCAT previously described. Each 5 grapheme and 5 colour set used in this experiment for each participant (including control participants) was unique to that participant and only graphemes for which the participant showed consistency were used. No participants reported any colour association for the tilde symbol.

Stimuli were presented under three different conditions in the Experiment: Congruent, Incongruent and Neutral.

The congruent condition: the colour of the presented grapheme was consistent with the association that the participant had made previously. Each was presented 8 times giving 40 congruent stimuli per block.

The incongruent condition: the colour of the presented grapheme was a colour that belonged to a different grapheme in the set than the one that the participant had selected. Each was presented in one of the incongruent colours twice, making 8 trials for each grapheme giving 40 incongruent trials per block.

The neutral condition: the tilde (~) symbol (the equivalent to the neutral XXXX in traditional Stroop experiments; (MacLeod, 1991) was presented in one of the five colours associated with a grapheme for that participant. Each stimulus was presented 8 times giving 40 neutral stimuli in each block. An illustration of the stimuli used for participant AK is provided in Figure 4-1.

Congruent A M S 2 7
Incongruent A M S 2 7 A M S 2 7 etc
Neutral ~ ~ ~ ~ ~

Figure 4-1. Illustration of stimuli used in the synesthetic Stroop experiments for participant AK: The 5 graphemes used were: A (red), M (pink), S (yellow), 2 (green), 7 (blue). A congruent trial was 'A' presented in red and an incongruent trial was comprised of 'A' presented in either pink, yellow, green or blue.

Because Stroop interference can be reliably produced by using the initial letter of a colour word in both synesthetes and controls, (Lupianez & Callejas, 2006), care was taken to avoid grapheme to colour combinations by the participant in which the grapheme was the first letter of the word used to denote the colour. For instance, we avoided a colour combination of B in blue or R in red. (this inadvertently occurred for 3 participants with one letter each and the congruent trials were removed from the analysis).

4.4.1.3. Presentation

Stimuli were designed and presented using Matlab and the PsychToolbox 3.0.8 (Brainard, 1997; Pelli, 1997) in the centre of a Sony Trinitron G520 monitor and subtended an angle of approximately 1 degree. Participants were seated 1 metre from the screen and used a chin rest. Responses were recorded via a microphone attached to the chin rest and an individual sound file was created for each response.

The design of the stimulus presentation follows the traditional Stroop paradigm where each stimulus class is presented an equal number of times. Each block comprised 120 trials (40 congruent, 40 incongruent and 40 neutral). Participants completed between 3 and 5 blocks. Participants were instructed to report the colour that was presented on the screen and to ignore the letter.

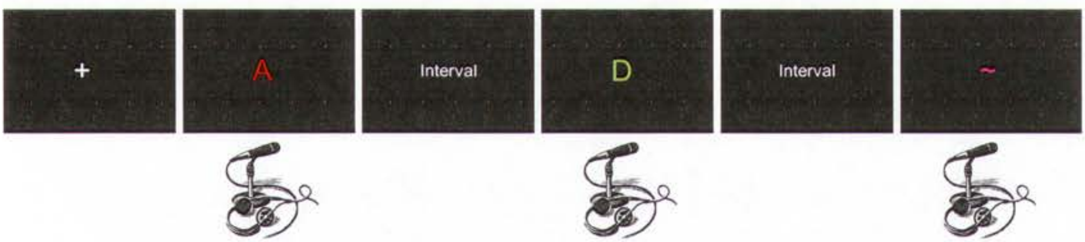

Figure 4-2. Illustration of synesthetic Stroop screen colour naming experiment procedure

Figure 4-2 illustrates the procedure for Experiment 5. The block commenced with a fixation cross, then a variable random inter-trial interval of up to 1000ms followed by a coloured grapheme for 1500ms. An additional pause interval of 500 ms was included before the next fixation cross and variable interval followed by the coloured grapheme of 1500ms. Responses were collected and recorded automatically. A block continued until all 120 grapheme responses were collected.

4.4.1.4. Data Collection and Analysis

Response times (RTs) were determined through a semi-automated procedure and determined as the difference between the onset of the visual stimulus and the commencement of the participant's verbal response.

All files which showed a premature response from the participant such as an extraneous utterance or where the participant had made an error were removed from the analysis. Where the automated process gave an incorrect response time by picking up extraneous background noise the procedure was supplemented by a careful manual checking and editing of each individual response. 3% of trials overall were removed from the analysis, 50% of these due to technical issues with the file (such as background noise that could not be eliminated). The remainder were either utterances or incorrect responses.

A median RT was determined for each participant for each condition across all the successful trials. Each data class was examined in its own right for investigations of main effects and interactions but transformed variables were also created to assist in interpretation and to smooth the progress of a discussion that is consistent with the Stroop literature. These transformed variables are: Facilitation (congruent minus neutral), Interference (incongruent minus neutral) and Congruity (incongruent minus congruent).

4.4.2. Results

Hypotheses in Experiment 5 were tested using a 2 (group: synesthetes, controls) * 3 (conditions: congruent, incongruent, neutral) repeated measures ANOVA with alpha levels set to 0.05. One control participant's median data for each condition was found to be a significant outlier (>2.8 SDs) and it was removed from the analysis. Figure 4-3 shows the mean RTs and standard errors (S.E.) for each condition and for each group.

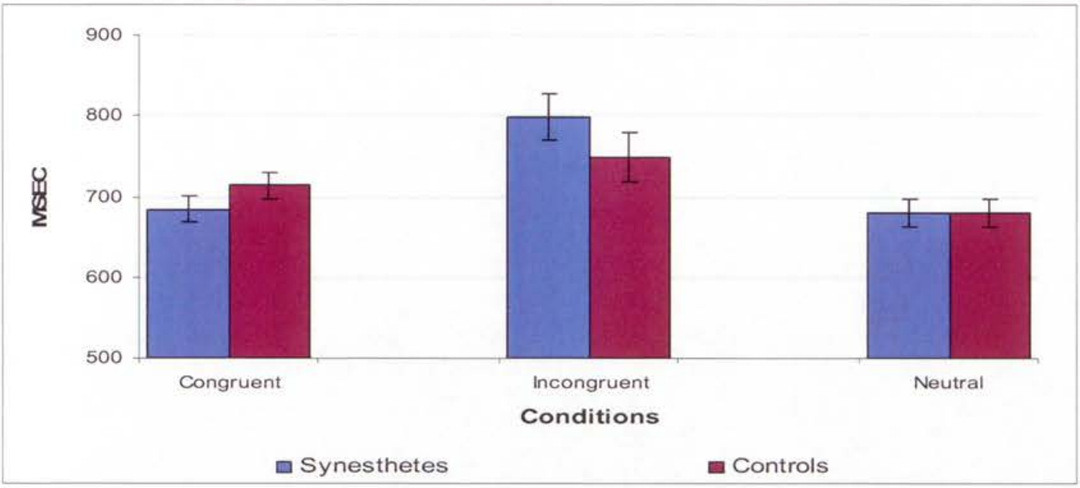

Figure 4-3. Mean and S.E. of RTs for synesthetes and controls in Experiment 5 for three conditions: congruent, incongruent and neutral. Error bars represent one S.E. of the mean.

After adjusting for sphericity (using Greenhouse-Geyser) there was a main effect for condition ($F(1.15, 42.41) = 26.83$, $p < 0.001$) and an interaction between group and condition ($F(1.15,42.41) = 4.403$, $p = 0.037$).

Congruity Effects

Congruity effects (incongruent minus congruent) were investigated using a independent samples t-test. In keeping with previous synesthetic Stroop research, Figure 4-4 shows that synesthetes have a larger congruity effect than controls. ($t(37) = 2.370$, $p = 0.02$).

Importantly, post hoc analysis of the congruity effect examining the control group shows a significant difference between the two conditions ($t(19) = 3.86$, $p < 0.001$) Thus control participants show a synesthetic Stroop congruity effect when a stimulus ensemble unique to their own grapheme-colour selections is used.

The level of the congruity effect was examined in relation to the colour match consistency score of the participants in the GCAT and found that there was no significant correlation for either synesthetes or controls. (both p values > 0.14)

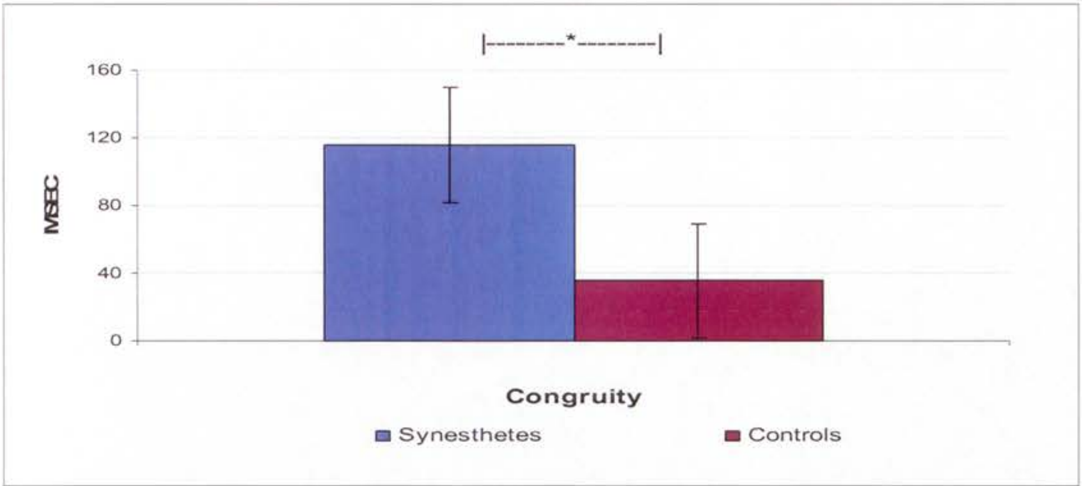

Figure 4-4. Mean and S.E. of RTs of congruity effect for synesthetes and controls: Experiment 5. Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

Interference Effects

Interference effects (incongruent minus neutral) were investigated using a independent samples t-test. Figure 4-5 shows that synesthetes appear to show a larger interference effect than controls. However, the difference does not reach significance ($t(37) = 1.651$, $p = 0.106$).

The level of the interference was examined in relation to the colour match consistency score of the participants in the GCAT and found that the level of interference is correlated with the GCAT score for controls (N = 19, $r = -0.462$, $p = 0.046$) indicating that the stronger the colour match consistency score the more an interference effect is seen. After the removal of one synesthete outlier[15] a marginally significant correlation for synesthetes is also found (N=19, $r=-0.431$, $p = 0.065$).

In conclusion, both groups experience synesthetic Stroop interference, neither group more significantly than the other. Generally, the more consistent a participant is in matching colours to graphemes the more interference is seen.

[15] RT was >3SD above synesthete group mean

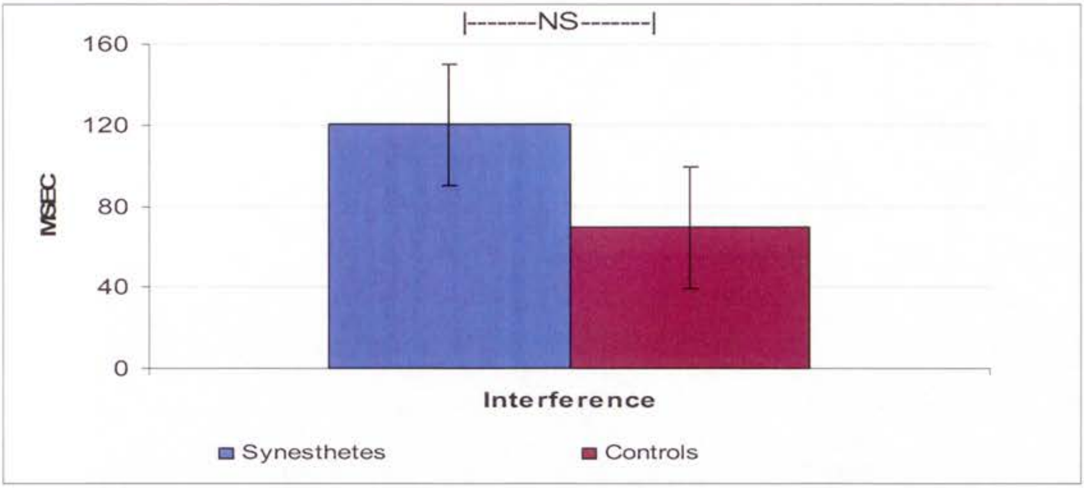

Figure 4-5. Mean and S.E. of RT for interference effect for synesthetes and controls: Experiment 5. Error bars represent one S.E. of the mean. NS indicates that indicates there was not a statistically significant comparison.

Facilitation Effects

Facilitation effects (congruent minus neutral) were investigated using a independent samples t-test. There is a significant difference between the groups with regard to facilitation ($t(37) = -2.816$, $p = 0.008$) with the control group showing "reverse" facilitation (congruent > neutral) in general (synesthetes: N = 19, M = 4.38, S.E. = 7.99; controls: N = 19, M = 34.16, S.E. = 6.86). This can be seen in Figure 4-6. This indicates that control participants have a cost in processing different grapheme stimuli over processing the single tilde symbol, a difficulty that the synesthete group does not appear to have.

Only one control participant shows traditional facilitation (congruent < neutral) but at an extremely low level (2.6ms), whereas 8 synesthete participants show 'traditional' facilitation effects (ranging from 0.3 to 112 MS).

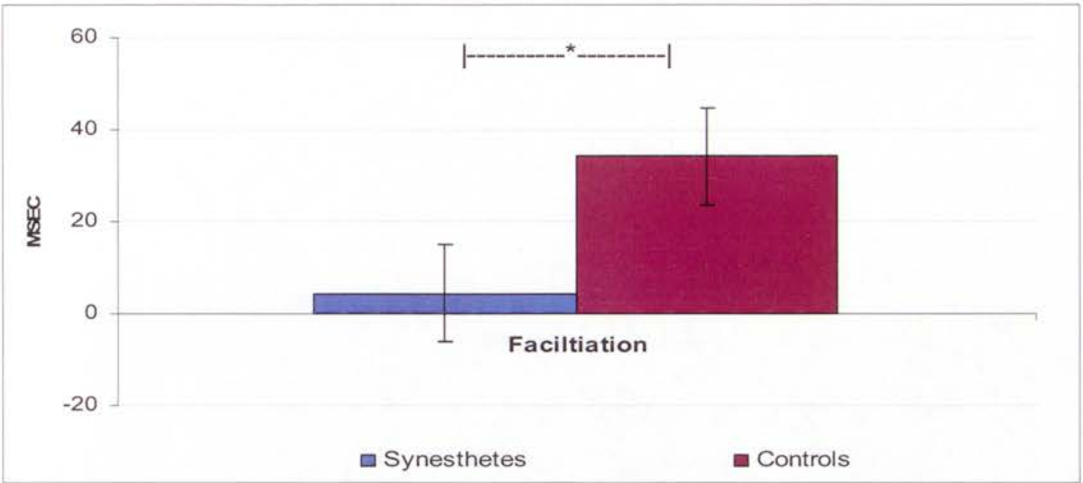

Figure 4-6. Mean and S.E. of RT for facilitation for synesthetes and controls: Experiment 5. Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

The level of the facilitation was examined in relation to the colour match consistency score of the participants in the GCAT. No relationship was found for synesthetes (N = 19, $r = 0.108$, $p = 0.659$) nor for controls (N = 19, $r = 0.024$, $p = 0.923$).

4.4.2.1. Post Hoc Analysis for Tectonic Effects - Experiment 5

In this section we examine whether there are tectonic effects in our experiment. We wish to know whether the choice of our Stroop design is influential in deriving the Stroop effects seen in our experiment. Our analysis examines the Stroop effects at both the commencement and the end of the experiment. Our aim is to uncover if any changes in Stroop effects are consistent with tectonic influences.

One synesthete and four controls data whose first block was restarted, or had been removed from the main analysis due to response or technical difficulties were removed from the analysis.

A RM ANOVA revealed a main effect for congruity (adjusted for sphericity) ($F(1.45, 46.25) = 12.91$, $p < 0.001$), an interaction between congruity and time ($F(2,64) = 3.478$, $p = 0.04$), and a group by time by congruity interaction ($F(2,64) = 3.265$, $p = 0.045$). There was no main effect for group nor for time.

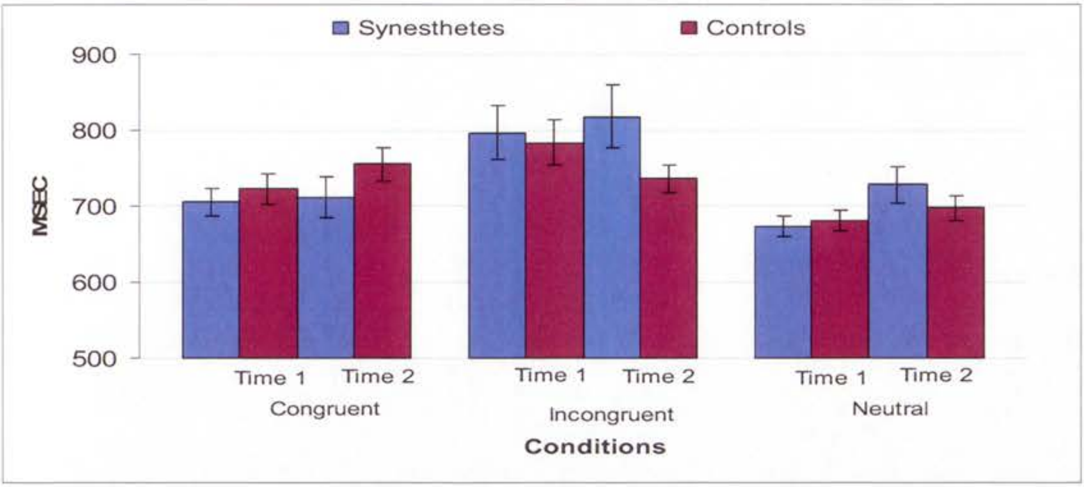

Figure 4-7. Mean and S.E. of RTs for synesthetes and controls as a function of condition (congruent, incongruent, neutral) for time 1 and time 2. Error bars represent one S.E. of the mean.

Both synesthetes and controls response times at T2 are higher than at T1, except in the incongruent condition for the control group. None of the increases are significant (all p values > 0.23 uncorrected) except for the increase in the neutral condition for synesthetes ($t(18) = -2.51$, $p = 0.022$ uncorrected).

Congruity, facilitation and interference values were derived and assessed separately as a 2 (group) * 2 (time) ANOVA. All reported *p* values were adjusted for multiple comparisons using the Bonferroni method and Greenhouse-Geisser corrections were used where sphericity cannot be assumed.

Congruity Effects

A 2 (group) by 2 (time) RM ANOVA for congruity revealed no main effect for time and a significant interaction ($F(1,32) = 5.32$, $p = 0.03$). Pairwise comparisons revealed a difference between the groups at T2 (mean difference = 125.32, $p = 0.014$), and a difference for controls only across the two time periods (mean difference = 79.597, $p = 0.014$). Importantly, at T1 there was a marginally significant difference between congruent and incongruent RTs ($t(14) = -2.09$, $p = 0.056$) for controls. The effect of congruity for synesthetes does not change between T1 and T2 (Mean difference = 14.58, $p = 0.59$), and only the synesthetes have a significant congruity effect at the end of the experiment (synesthetes: $t(18) = 2.56$, $p = 0.02$, controls: $t(14) = -1.413$, $p = 0.18$). The GCAT scores were not correlated to any congruity by time measures for either group (all p values > 0.05).

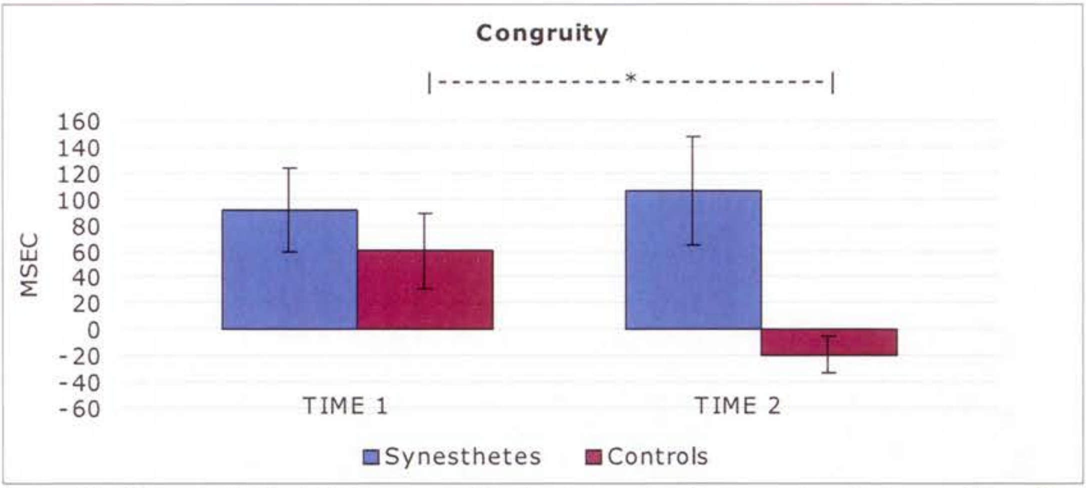

Figure 4-8. Mean and S.E. of RT for congruity effect for synesthetes and controls over time. Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

Interference Effects

A 2 (group) by 2 (time) RM ANOVA for interference revealed a main effect for time ($F(1,32) = 6.51$, $p = 0.016$) and no interaction ($F(1,32) = 0.60$, $p = 0.44$). Neither group is significantly different to one another at either time period (all *p values* > 0.28) although only the control group has a significant decrease in interference from T1 to T2. (Mean difference = 63.66, $p = 0.033$). Importantly both groups still showed Stroop interference at T2 as evidenced by one sample t-tests for each group (synesthetes: $t(18) = 2.3$, $p = 0.034$, controls: $t(14) = 2.203$, $p = 0.045$). The GCAT scores were not correlated to any interference by time measures for either group (all *p* values > 0.05).

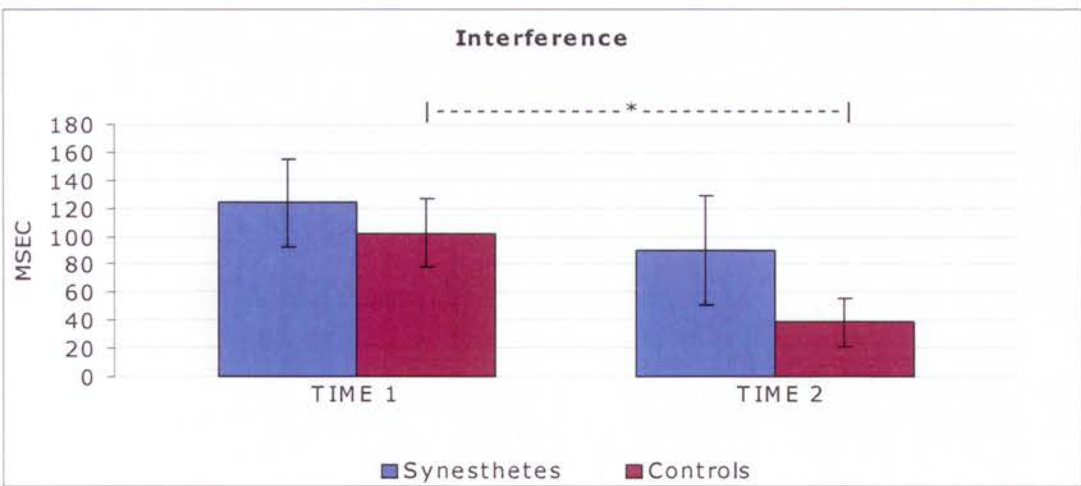

Figure 4-9. Mean and S.E. of RT interference effect for synesthetes and controls over time. Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

Facilitation Effects

A 2 (group) by 2 (time) RM ANOVA for facilitation revealed no main effect for time and a marginally significant interaction between condition and group ($F(1,32) = 3.67$, $p = 0.06$). Pairwise comparisons revealed a difference between the groups only at T2 (mean difference = 74.145, $p = 0.028$, and a difference only for synesthetes across the two time periods (mean difference = -48.529, $p = 0.037$). The GCAT scores were not correlated to any facilitation by time measures for either group (all p values > 0.05).

Examination of the raw data shows that there are increases in RT for both congruent and neutral conditions for both groups but a paired t-test reveals a significant difference in neutral RT only for synesthetes between T1 and T2. ($t(18) = -2.448$, $p = 0.025$). These increases possibly reflect fatigue. However, it is curious that the change is significantly larger for synesthetes than for controls.

All but one synesthete showed an improvement in facilitation from T1 to T2 (range from: 2.1 to 318 ms), whereas only 9 of 15 controls show this effect (also with a narrower range: from 10 to 82 ms). In general, synesthetes transition from reverse facilitation at the commencement of the experiment to traditional facilitation at the end of the experiment. This result is due to the increase in RT for neutral trials rather than any specific gain in RT on congruent trials.

Given the importance of interpreting facilitation data for synesthetes we examined whether there was a relationship between facilitation gains and interference losses for each group as this would be suggestive of a common mechanism driving the congruency effect. There was no significant correlation between facilitation change and interference change for controls $r = 0.14$, $p = 0.58$. There was a marginally significant relationship for synesthetes $r = -0.425$, $p = 0.062$. Synesthetes either lose the interference effect or gain facilitatory effects but not both. Control participants simply lose interference effects.

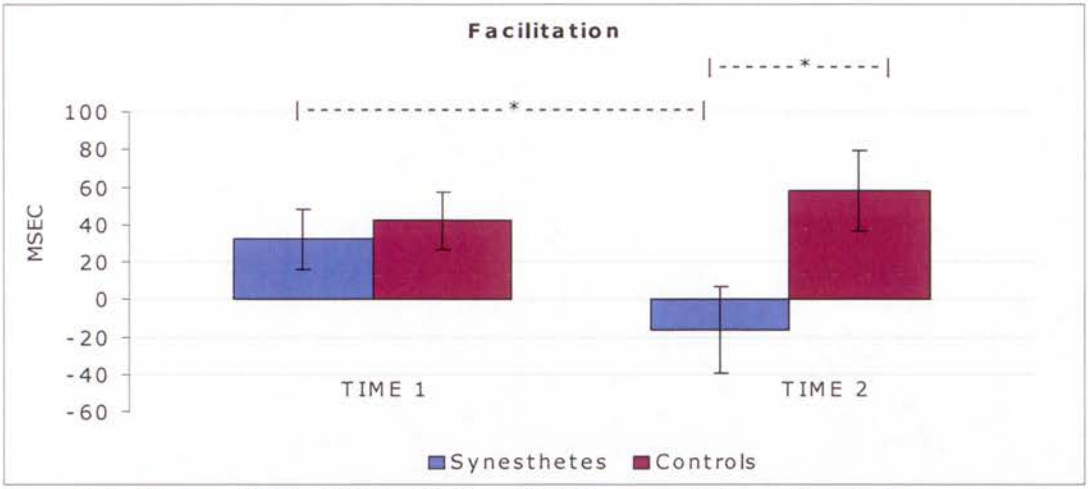

Figure 4-10. Mean and S.E. of RT facilitation effect for synesthetes and controls over time. Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

4.4.3. Discussion - Experiment 5

Experiment 5 was designed to address a major claim in the literature: that the synesthetic Stroop effect is a unique cognitive marker for synesthesia and is a measure of its genuineness. The main result reported in this experiment is that control subjects exhibit synesthetic Stroop congruity and interference effects. This is consistent with the conclusion that the synesthetic Stroop effect may not be a diagnostic cognitive marker for idiopathic synesthesia as has been previously claimed.

Our testing paradigm was designed to overcome limitations in previous designs. Firstly, that current methods to test the automaticity of synesthesia did not control for important aspects of the paradigm by using a baseline condition. Secondly, that control participants ability to associate (or translate from) one dimension (a grapheme) with another (a colour) should have formed the basis of the control condition in the paradigm.

The overall result shows a main effect for condition and an interaction suggesting that the different conditions may affect synesthetes and controls differently. The use of a neutral baseline condition in this experiment allows a deeper investigation of the source of the differences between the groups and from which an examination of the effects of facilitation, interference and the traditional congruity effect could be made.

The congruity effect is the measure the vast majority of synesthetic Stroop studies report and is the result that would form a direct comparison. Overall both groups experience a congruity effect but to different extents. Synesthetes experience a larger difference in the RT between congruent and incongruent conditions. In short, controls demonstrate a congruity effect when a relevant stimulus ensemble is used. Overall congruity effects were not related to colour match consistency scores of the GCAT, suggesting that a connection between Stroop congruity effects and the ability to match colours to graphemes is mediated by other factors.

Despite the fact that synesthetes mean interference RT was larger than that of controls the difference between the groups was not significant. This is an interesting finding, suggesting that the Stroop effects seen in synesthetes in previous studies might be due largely to conflict resolution and reporting of items which are incongruent. This is a result consistent with the conclusions drawn from previous research but which were confounded by a lack of baseline comparison. Interference was related to the colour match consistency score for controls and marginally for synesthetes, suggesting that the relationship between the Stroop interference effects and the ability to match colours to graphemes are related in such a way that the more consistently colour matches are made the more difficulty is experienced in naming colours of graphemes than colours of neutral stimuli. This further supports the general contention that the effect is one of a categorical rather than perceptual nature as it is a fact shared by both groups. That interference is experienced equally between the groups suggests that the Stroop interference effect might not be due to low-level perceptual (synesthetic) influences but is largely due to conceptual or categorical processes.

The results of Experiment 5 are consistent with those of Elias et al., (2003) who demonstrated that controls can show Stroop effects after training. However, we do not fully agree with their statement that synesthetes and controls cannot be differentiated using this task. The data for congruity effects over time in Experiment 5 show that controls exhibit congruity effects at the beginning of the experiment and that these congruity effects decline by the end of the experiment. Synesthetes, on the other hand, have congruity effects both at the beginning and at the end of the experiment. In fact the loss of the congruity effect in the control group is due to both a loss of interference and a cost of facilitation. Synesthetes gain facilitation significantly and do not lose interference significantly. At the commencement of the experiment both groups exhibit reverse facilitation taking longer to process congruent than neutral stimuli. But as trials accumulated and the experiment progressed the synesthetes gain advantages in the congruent condition relative to the neutral condition. Even though the only significant increase from T1 to T2 was for synesthetes' neutral trials, all conditions RTs increased except the synesthetes congruent condition. The most parsimonious explanation is that RTs increase across all conditions due to fatigue and that the lack of increase in congruent RTs is due to processing gains within that stimulus condition. This is a result which would be predicted by the covariance matrix of our design, but it is not seen for the control group who received matched conditions. This makes the design influence as a sole explanation unlikely. It is more likely that synesthetic associations (either conceptual or perceptual) do arise in the experiment and influence conceptual processes for synesthetes and these do not occur in the control group to the same extent. One other observation about facilitation is worth mentioning. According to Macleod (1991) the reason most experiments fail to find facilitation may well be due to the fact that this is already a fast and automatic process which is difficult to speed up. In other words speed may already be at ceiling. The inclusion of a neutral stimulus – along with long blocks of trials - may assist in driving up the RTs of other conditions (possibly due to fatigue) which then reveal a relative increase in facilitation. Future studies will be required to tease out this proposition.

The result that control participants appear to lose a significant amount of interference at T2 would be predicted as the controls presumably have less durable or weaker associations between graphemes and colour and there is presumably no perceptual interaction between the stimulus dimensions.

In summary, in this experiment, three results are most interesting. First, there is a lack of a difference between groups in interference RTs at both time periods and interference correlates with the colour match consistency score. Secondly, there are gains in facilitation related to higher neutral RTs for synesthetes and third there is an overall loss of the congruity effect for controls related to the combined effect of lost interference (which was significantly different between time periods) and lost facilitation (which was not significantly different between time periods). These facts combined suggest that there is still room to learn from the synesthetic Stroop paradigm.

We can conclude with a reasonable level of confidence that the covariate design of this experiment did not drive the family of Stroop effects found in our experiment and that the results truly reflect the experimental manipulation for two reasons. First the effects in the overall experiment are seen in the first 10 trials of each condition. Second when the last 10 trials of each condition were examined the predicted effects of the positive covariance matrix design did not eventuate. To be certain of the lack of influence of the covariance design, other designs which manipulate both congruity types and examine attentional effects over time in synesthetes need to be conducted. We propose one further conclusion, that these results indicate a lack of support for this aspect of tectonic theory of Stroop effects or at least indicate a need to examine it further. As noted previously, most synesthetic Stroop studies use congruity effects without the inclusion of neutral stimuli, so a replication of these results is warranted.

A final opportunity for exploration was taken in the data analysis of this experiment. This was to examine whether there were any relationships between colour match consistency and any of Stroop effects which might be seen in the experiment. In this experiment we do not see differences in the amount of interference experienced between synesthetes and controls but we do find that interference is related to colour match consistency. In short, the average consistency of colour matching in the GCAT negatively correlates with interference in the synesthetic Stroop colour naming experiment. A simple conclusion might be that there are no differences in response conflict experienced between the groups when consistent grapheme-colour stimuli are chosen individually for each participant. A likely explanation is that the GCAT is a measure of the strength of the consistency of the association. That this is a strong correlation particularly for controls indicates that the level of interference experienced by participants is related to the consistency of association not the perceptual features of synesthesia. It therefore implies that the general argument that synesthetic Stroop experiments measure the automaticity of synesthesia needs refinement to become more specific as a measurement of the relationship of the associations between stimulus dimensions (in this case graphemes and colour) in synesthesia.

4.5. Experiment 6 - Synesthetic Stroop Associated Colour Naming

The associated colour naming experiment has a long history in the synesthetic Stroop literature. In this experiment participants are asked to view congruently or incongruently coloured graphemes and to report the colour that they associate with the grapheme. The experiment is not conducted with a neutral baseline condition. Therefore only one Stroop effect is produced in the experiment and that is the congruity effect. The performance of control subjects in this experiment have not been compared to the performance of synesthetes because previous researchers have neglected to test control subjects reasoning that that control subjects do not have any coloured concurrents to name (Esterman, Verstynen, Ivry, & Robertson, 2006;

Lupianez & Callejas, 2006). Even though control subjects do not have concurrents that they can name, they do have consistent associations of colour to graphemes that they could name. Experiment 6 was undertaken to determine whether controls as well as synesthetes would exhibit this congruity effect when they are administered a stimulus ensemble derived from the colour matches that they made in the GCAT.

4.5.1. Method

4.5.1.1. Participants

Eleven control participants and 20 grapheme-colour synesthetes were recruited for the associated colour naming experiment. Participants volunteered and were reimbursed $20 per hour of testing or received course credit for the time involved. Participants gave written informed consent and the study was approved by the Human Research Ethics Committee of the University of Sydney. Participants were naive to the manipulation of the experiment.

All participants in Experiment 6 were participants in Experiment 5. Synesthetes completed the experiments on different days. Controls completed this experiment on the same day as Experiment 5. The order in which the experiments were completed was counterbalanced, with 6 of the 11 controls undertaking Experiment 5 first.

4.5.1.2. Stimuli, Presentation and Data Collection

Stimuli were designed and presented using Matlab and the PsychToolbox 3.0.8 (Brainard, 1997; Pelli, 1997) in the centre of a Sony Trinitron G520 monitor and subtended an angle of approximately 1 degree. Participants were seated 1 metre from the screen and used a chin rest. Responses were recorded via a microphone attached to the chin rest and an individual sound file was created for each response. Stimuli examples were shown in Figure 4-1 but the tilde symbol is not used in this experiment.

The unique stimulus ensemble created for every participant, described in Experiment 5, were used in this experiment. Each block was administered in exactly the same way as in Experiment 5 except that the neutral stimulus (tilde) was not used. Each block was therefore comprised of 80 trials (40 congruent condition trials and 40 incongruent condition trials). Participants completed between 3 and 5 blocks. Participants were instructed to ignore the colour and to state the colour of their own association for the grapheme presented.

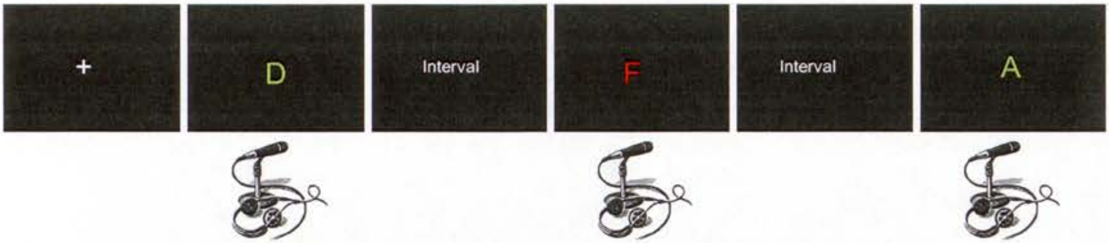

Figure 4-11. Illustration of synesthetic Stroop associated colour naming experiment procedure

Figure 4-11 illustrates the procedure for Experiment 6. The block commenced with a fixation cross, then a variable random inter-trial interval of up to 1000 ms followed by a coloured grapheme for 1500ms, giving participants enough time to respond. An additional pause interval of 500 ms was included before the next fixation cross and variable interval followed by the coloured grapheme of 1500ms. Participants were instructed to respond to the grapheme by stating the colour of their association to it. Responses were collected and recorded automatically via microphone. A block continued until all 80 grapheme responses were collected. Less than 3% of trials overall were removed from the analysis, over 50% of these due to technical issues with the file (such as background noise that could not be eliminated). The remainder were utterances or incorrect responses. These were often responses where the screen colour of the grapheme was named. There were too few for analysis and are therefore not discussed further.

Data collection procedures were the same as those described in Experiment 5.

4.5.2. Results

A 2 (group) by 2 (condition) RM ANOVA revealed a main effect of condition ($F(1,29) = 205.55$, $p < 0.001$) and no interaction ($F(1,29) = 1.27$, $p = 0.27$). Both groups show a congruity effect.

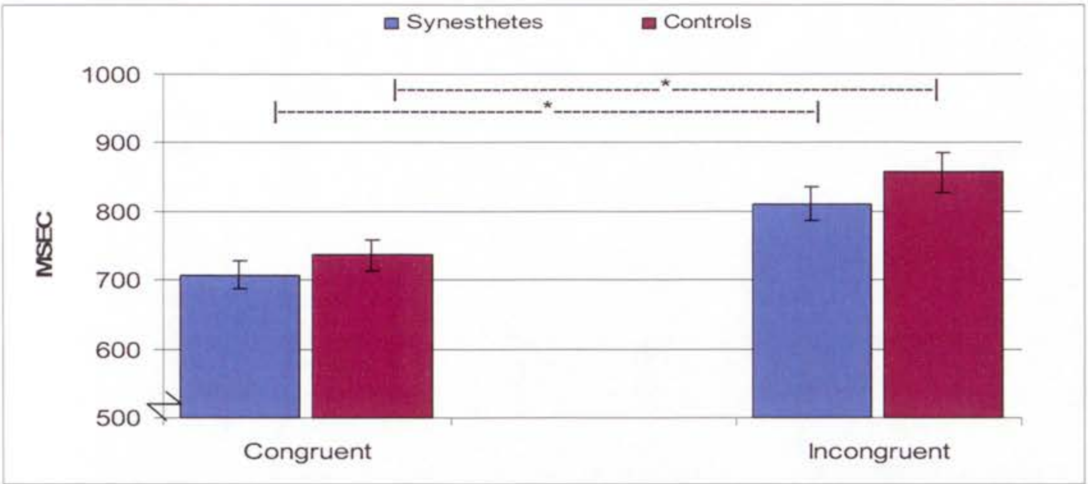

Figure 4-12. Mean and S.E. of RTs for congruent and incongruent conditions for synesthetes and controls: Experiment 6. Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

4.5.2.1.1. Analysis for Tectonic Effects

2 participants (1, synesthete and 1 control) whose first block was restarted were removed from the analysis. A 2 (condition) by 2 (time) by 2 (group) RM ANOVA revealed main effects for condition ($F(1,27) = 89.27$, $p < 0.001$), and time ($F(1,27) = 10.4$, $p = 0.003$), and a non significant interaction for condition by time by group ($F(1,27) = 2.94$), $p = 0.098$).

The groups were analysed separately to assess the changes in conditions over time. The 2 (condition) by 2 (time) RM ANOVA revealed a significant effect for condition ($F(1,9) = 48.97$, $p < 0.001$) but no significant effects for time or interactions for the control group. Thus we conclude that the control groups performance from the beginning of the experiment to the end does not change between the conditions. For our synesthete group however, there are main effects for condition ($F(1.18) = 46.22$, $p < 0.001$), time ($F(1,18) = 9.84$, $p = 0.006$), and an interaction between them ($F(1,18) = 11.707$, $p = 0.003$). A paired t-test to examine the congruity effect (incongruent-congruent) over time (T1 - T2) reveals a decrease in the RT of the incongruent condition at T2 ($t(18) = 3.422$ $p = 0.003$). In short both groups show decreases in RT's across the experiment (in both conditions) but the decrease is significant only for the synesthete group.

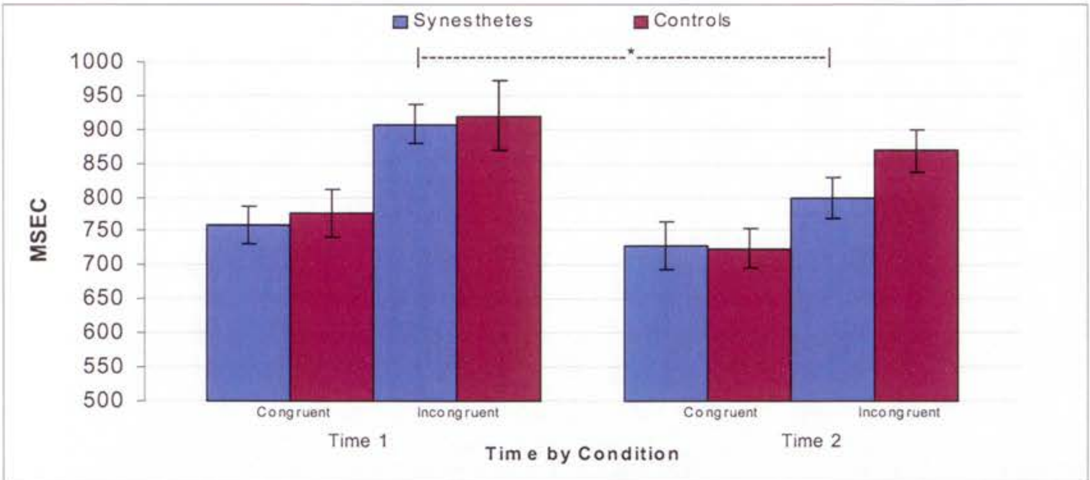

Figure 4-13. Mean and S.E. of RTs for synesthetes and controls by condition (congruent, incongruent) and time (time 1, time 2) for Experiment 6. * indicates a statistically significant comparison.

4.5.3. Discussion - Experiment 6

The purpose in conducting Experiment 6 was to examine whether control subjects experience Stroop congruity effects in the associated colour naming task, an experimental manipulation never previously undertaken. The results clearly show that both synesthetes and controls experience difficulty naming their associated grapheme-colour when they are required to identify and process a distractor stimulus presented in a colour incongruent with their own. Importantly it shows that there is no difference in the level of congruity between the groups.

A fundamental limitation of this experiment, like the ones that have gone before it, is that there is no baseline condition in this paradigm. However, introducing a baseline condition in the associated colour naming experiment may actually be possible. This could be achieved by including graphemes for which 'no colour' is reported and asking the participant to give the response none. Given the covariance matrix of our experimental design, it was also possible that the congruity effect could be due to control participants being over exposed to specific congruent stimuli which would drive up its predictability in the experiment. For the same reasons as in Experiment 5, this data was subject to an analysis of the first 10 trials of the first block for each condition and the last ten trials of the third block for each condition. If the covariance matrix was influential in the result then no difference between the conditions or groups at the outset of the experiment should be apparent. The congruity effect would need to build throughout and a gain in RTs in congruent stimuli as they become predictive would be expected. This did not occur. Therefore we conclude, that the tectonic design of the experiment is not the main cause of the congruity effect.

Our result does seem consistent with the single case study of Lupianez & Callejas (2006) for whom negative priming eliminated the congruity effect in an associated colour naming experiment. Despite the fact that there was no control group for comparison in the Lupianez & Callejas (2006) study, our synesthetes' data is consistent with theirs in that no congruent condition improvements are seen. A conclusion Lupianez & Callejas, (2006) drew was that that the synesthetic association has preferential access to consciousness or was stronger than the real colour. This might account for the fact that synesthetes are slightly (but not significantly) faster in this experiment than controls, but cannot account for why synesthetes' incongruent trials get faster preferentially over the congruent ones. The simplest explanation for the fact that effects are seen to accrue differently for the synesthetes across conditions is that synesthetes are better at dealing with or ignoring distracting information in the external environment particularly when fully attending to their own internal representations. This explanation is consistent with incongruency being a function of response conflict. Further, a capacity for absorption results in a better ability to ignore inconsistent distracting stimuli when attending to one's internal perception/imagery. "The absorbed individual often seems not to notice external events that would normally draw attention. This too could be seen as inherent to having an already fully committed representational system" (Tellegen & Atkinson, 1974). Whether synesthetes have a higher capacity for absorption and thus a greater invulnerability to normally distracting events has not been tested in a verified group of idiopathic synesthetes, and is a proposition we test in Chapter 6.

Some support for this idea comes from the reports of synesthetes themselves. Some synesthetes complained that the incongruent condition in the colour naming experiment was very distracting and that they become uncomfortable. In this experiment participants were forced to attend to the external environment to give a response in the distracting dimension. No such complaints or observations were made in the associated colour naming experiment where participants were reporting on their own internal imagery not an external stimulus. Attending to their own grapheme-colour association is a practiced activity for synesthetes, particularly for those who report that it is useful for memory. The requirement in this task was that the participant be able to focus their attention on their own mental imagery or concepts. Synesthetes have been shown to have stronger mental imagery than controls (Barnett & Newell, 2008). A capacity for absorption in everyday activities and mental imagery is also highly correlated (Crawford, 1982). In short, synesthetes prefer the task which focuses on their own internal imagery and in which they are able to tune out or ignore the distracting incongruent external stimuli (colour). They may have a greater capability to do so than controls.

4.6. Experiment 7 - Geometric Shape to Colour

4.6.1. Introduction

In our discussions with synesthetes it became clear that many different types of categorical information can be inducers for synesthesia. In Chapter 3 it was shown that graphemes that are orthographically similar can share the same colour. Notably this was the more obvious for graphemes which have simple geometric properties (O, I, A). A projector grapheme-colour synesthete participant (JK) in Experiment 1a reported projected concurrent colours for geometric shapes, thus providing the opportunity to investigate whether this type of synesthesia manifests in a similar way to other types, particularly graphemes. She also reported that the projected concurrent synesthetic colours geometric shapes were weaker than those elicited by graphemes. To date, there is no published study assessing whether shapes (outside of graphemes) can genuinely induce synesthesia, although there is a single case report of coloured circuit diagrams in an online electronics magazine. Maxfield (2007) reports the case of an electrical engineer who perceives different colours when looking at gate-level schematic diagrams such as the one in Figure 4-14.

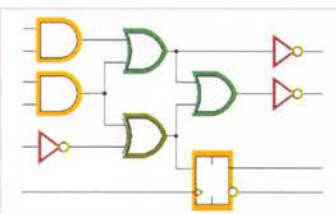

Figure 4-14 Synesthetically coloured schematic of electrical diagram (Maxfield, 2007)

4.6.2. Aims and Hypotheses

The aim of the following set of experiments was to examine, using the currently accepted tests (TOG and synesthetic Stroop) whether this case of synesthesia was genuine and whether the Stroop test could support her claim that the colour associations for geometric shapes were weaker than those elicited by graphemes. This was examined by:

- Designing and applying an internal consistency TOG of the colour associations for geometric shapes. If JK's associations are consistent, a score less than 1 should be achieved. This is reported as Experiment 7a.
- Determining whether the colour associations for geometric shapes were elicited 'automatically', by administering the two commonly used variants of the synesthetic Stroop paradigm. If JK's synesthesia is the product of automatic associations, Stroop interference and congruency effects, should be seen. These experiments are reported as Experiment 7b and 7c.
- Comparing her data from all 4 synesthetic Stroop experiments.

4.6.3. Participant

JK is a 21 year old female synesthete. She reports that she has had synesthesia since childhood. She advises that other members of her family also have synesthesia. She reports projected concurrent experiences. She advises that shapes do not induce synesthesia as strongly as graphemes, which are present "every time I read a book" and that she has only become aware of them more recently, not since early childhood. She has a number of forms of synesthesia including colour for graphemes (GCAT score = 0.41) and infrequent experiences of colour for music which are also projected. JK was naive to the manipulations of each experiment.

4.6.4. Experiment 7a - Geometric Shape Colour Association Test

Experiment 7a is a TOG for geometric shapes to colour synesthesia.

4.6.4.1. Method

The TOG was developed using the Matlab code provided in the downloadable Synesthesia Battery and was identical in nature to Experiment 1a except that filled black shape images were used as inducing stimuli. Solid black pictures of 20 different shape types (Appendix C) were presented and JK was asked to select the colour that best matched each shape in the test. We term this test the Shape Colour Association Test of Genuineness (ShCAT). Presentation of the stimuli and data collection and analysis were the same as those described for Experiment 1a.

4.6.4.2. Results

A total colour match consistency score of 0.34 was produced by the participant, well below the score of 1 which would most likely be recommended for this version of a CAT. All presented shapes were colour matched consistently. A follow up interview was undertaken with the participant after 14 months when she verified the colours originally selected for the main categories of shapes examined. Notably she has the same colour for similar basic shapes. Trapezium and square are blue; circles and ovals are yellow.

4.6.4.3. Discussion

This TOG suggests that the geometric shape concurrents of JK are consistently reported. The internal consistency paradigm TOG supports the self disclosure of JK. It is necessary to administer this TOG to control subjects in order to determine an appropriate diagnostic score as it is unknown to what extent control subjects could match colours to geometric shapes consistently. However if we assume that there is some consistency between TOG in terms of their diagnosticity, then a score under 0.7 would be strongly indicative of synesthesia and unlikely to be a false positive. Notwithstanding, JK was reassessed and reported the same colour associations for shapes over time.

4.6.5. Experiments 7b and 7c - Synesthetic Stroop Experiments for Shape Inducers

4.6.5.1. Method

The synesthetic Stroop experiments in Experiment 7b and 7c were developed using the same procedures for the synesthetic Stroop experiments described in Experiments 5 and 6 respectively. All procedures for stimuli presentation and data analysis used in Experiments 7b and 7c were also the same, except that shape images were used as stimuli instead of graphemes.

5 different shape colour matches for the synesthetic Stroop experiment were selected to be the inducing stimulus. In Experiment 5, the stimuli also included the tilde symbol as the stimuli for a control condition. JK reported no colour association for the tilde and therefore it was also used in Experiment 7b.

Stimuli were presented under three different conditions in the Experiment 7b (Congruent, Incongruent and Neutral) and 2 conditions in the Experiment 7c (Congruent and Incongruent).

The methods are also directly comparable to the design of the study by Macleod & Dunbar (1988) who found that Stroop interference for geometric shapes could only be elicited in control subjects after considerable training.

4.6.6. Experiment 7b - Synesthetic Stroop Screen Colour Naming For Shape Inducers

4.6.6.1. Results

JK completed 3 blocks of trials. Each block was automated and comprised of 40 congruent, 40 incongruent and 40 neutral trials. JK reported the screen colour of the presented shape and ignored its projected concurrent colour. No errors were made and there were no technical issues. No trials were removed from the analysis. A mean RT score was determined for each condition.

A repeated measures ANOVA showed that there was a significant main effect for condition $F(2,118) = 12.531$, $p < 0.001$). Figure 4-15 illustrates the decrease for the congruent condition (M = 605.2, S.E. = 10.85) over both incongruent (M = 673.73, S.E. = 11.92) and neutral (M = 614.78, S.E. = 8.68) conditions. Post hoc pairwise comparisons show significant differences between congruent and incongruent (Mean difference = -68.54, $p < 0.001$) and between neutral and incongruent (Mean difference = -58.96, $p < 0.001$) but there is no significant difference between, congruent and neutral response times (Mean difference = -9.581, $p = 0.472$).

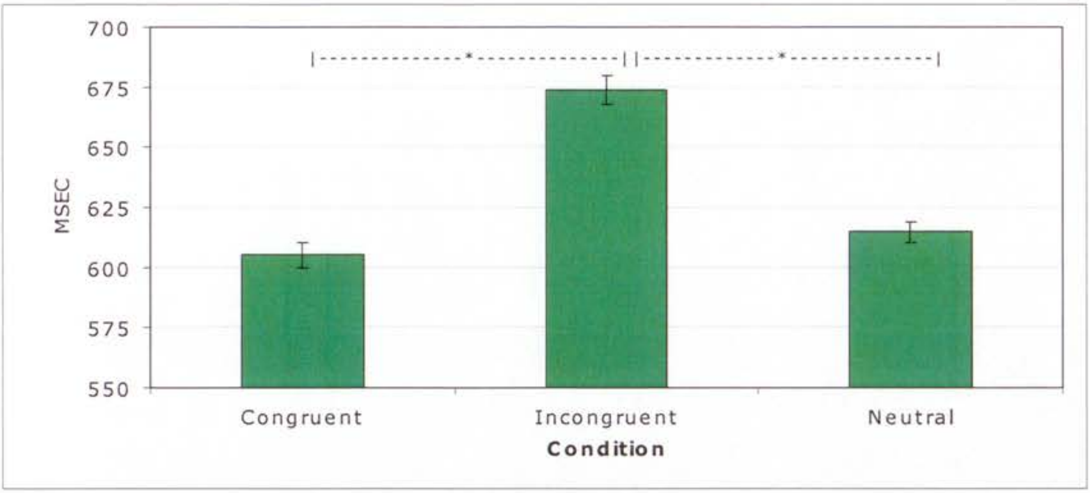

Figure 4-15. Mean and S.E. of RTs by condition (congruent, incongruent, neutral) for participant JK in Experiment 7b: the shape synesthetic Stroop screen colour naming experiment. Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

These results support the argument that synesthetic associations are difficult to suppress in so far as there is a disruption to processing when they are incongruently represented. This result is consistent with other reports of synesthetic Stroop effects in individual participants (Mills et al., 1999; Ward, 2004).

JK also participated in Experiment 5 in which graphemes were administered as inducing stimuli. A repeated measures ANOVA was conducted to compare her results across the two tests (graphemes and geometric shapes) using 3 (condition) * 2 (test type) factors. It revealed a main effect or test type $F(2,540) = 86.63$, $p < 0.001$ and an interaction $F(2,540) = 23.26$, $p < 0.001$. A t-test reveals a significant difference for incongruent trials between the tests $t(271.2) = -7.052$, $p < 0.001$.

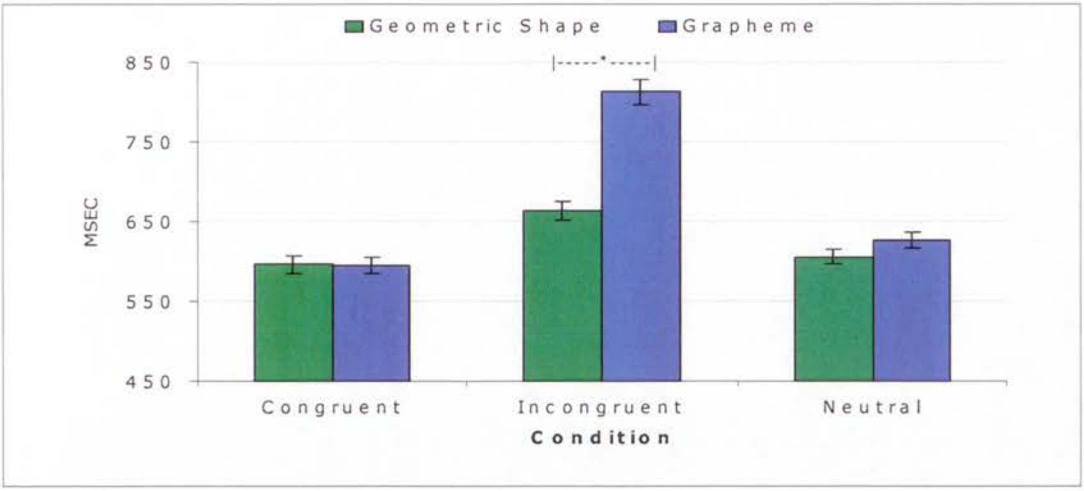

Figure 4-16. Mean and S.E. of RTs for geometric shape and grapheme synesthetic stroop screen colour naming experiment for each condition (congruent, incongruent, neutral). Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

Figure 4-16 shows that there is significantly less interference in the Stroop screen colour naming for shape images than in that for graphemes, suggesting shape associations may not be as strong as for graphemes. This is consistent with her reported experience.

4.6.7. Experiment 7c - Synesthetic Stroop Associated Colour Naming For Shape Inducers

4.6.7.1. Results

JK completed 3 blocks of trials comprised of 40 congruent and 40 incongruent items. JK ignored the screen colour and stated her projected concurrent colour for the shape presented. No errors were made and there were no technical issues. No trials were removed from the analysis. A mean RT score was determined for each condition.

One trial was removed from analysis as there was an incorrect utterance. A paired t-test determined that there was a significant effect for congruency $t(118) = -4.681$, $p < 0.001$. Figure 4-17 illustrates the larger response time for the incongruent condition (M = 612.53, S.E. = 12.90) over the congruent (M = 545.86, S.E. = 6.37).

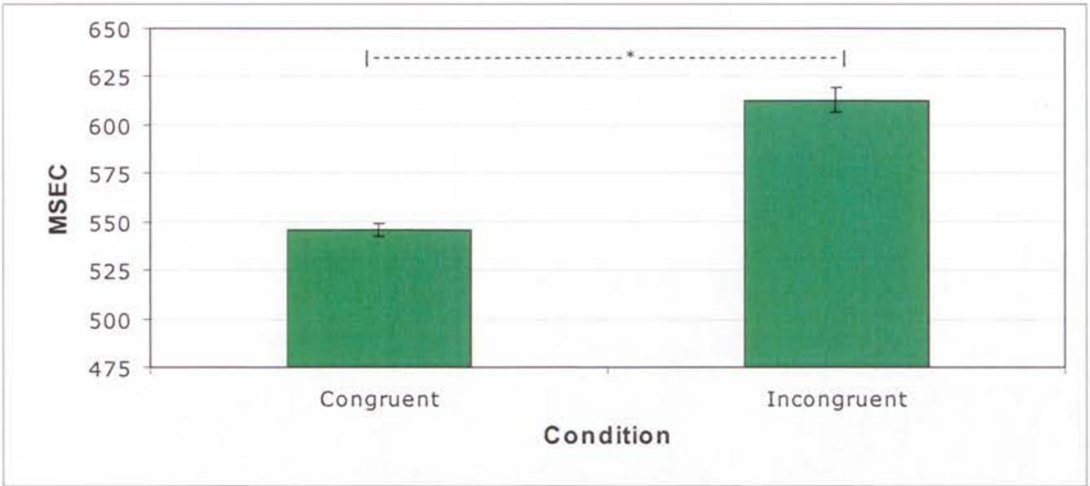

Figure 4-17. Mean and S.E. of RTs by condition (congruent, incongruent) for JK in Experiment 7c: the shape synesthetic Stroop associated colour naming experiment. Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

JK also participated in Experiment 6 in which graphemes were administered as the inducing stimuli. A 2 (condition) * 2 (test type) repeated measures ANOVA comparing the two tests across the two conditions was conducted. It revealed a main effect or test type $F(1,149) = 24.38$, $p < 0.001$. Figure 4-18 shows that synesthetic colours of graphemes were slower to name than the synesthetic colours of shapes. There was no interaction $F(1.149) = 0.002$, $p = 0.962$.

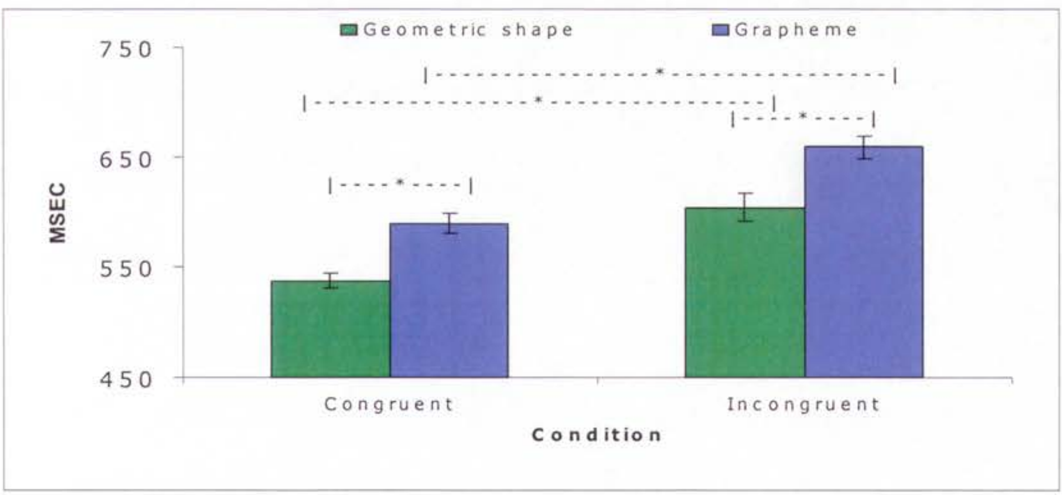

Figure 4-18. Mean RTs and S.E. by condition (congruent, incongruent) for geometric shape and grapheme synesthetic stroop associated colour naming experiments. Error bars represent one S.E. of the mean. * indicates a statistically significant comparison.

4.6.8. Discussion - Experiment 7

The results of the ShCAT test indicate that JK has internally consistent colour associations for shapes. The synesthetic Stroop tests support the assertion that these associations are automatically generated (rather than deliberately generated) and difficult to suppress.

This is the first time that synesthetic Stroop congruity and interference effects have been demonstrated for non-grapheme or non-musical stimuli. This again raises the question of whether the synesthesia might be the result of the physical shape of the stimuli, as would be the case in 'lower' synesthesia, or whether conceptual processes underlie it. It is possible that concurrent colours of geometric shapes are faster to name than concurrent colours of graphemes (as shown in Experiment 7c) because they are more rudimentary forms. More research is required to answer the question as the result could simply be due to the influence of participant variables (i.e. conducting the experiments on different days), rather than stimulus variables (shapes vs. graphemes). The comparison between the grapheme data and geometric shape data in experiment 7b which shows lower levels of interference for geometric shapes also confirms JK's claim that geometric shapes elicit weaker synesthesia than graphemes. These results support our earlier conclusion that the synesthetic Stroop effect reflects the strength of an association between two stimulus pairs and response conflict.

One interesting question for future study is whether the cortical areas giving rise to geometric shape synesthesia for this individual are the same as those which give rise to synesthesia for graphemes. Studies which compare different synesthesias within an individual have the potential to expand and refine theories which attempt to explain synesthesia. Specifically they may be able to address issues of local cross wiring, particularly if it is found that different classes of synesthetic inducers involve the same areas of the cortex in synesthesia.

4.7. General Discussion

The primary purpose for the experiments reported in this chapter was to assess the claim that the synesthetic Stroop effect is a unique cognitive marker, diagnostic of synesthesia. Our results show that synesthetes and controls cannot be readily differentiated in either the screen colour naming or the associated colour naming synesthetic Stroop tasks when consistent grapheme to colour associations, unique for each participant, are used.

Our results also suggest that Stroop effects (congruity, interference and facilitation) depend heavily on task demands within the experiment. When RTs are considered over the time course of the experiments, some evidence of differences between synesthetes and controls were found. Synesthetes appeared to be able to attend to their own associations to a greater extent than controls - as evidenced by facilitation gains in the colour naming experiment and a drop in incongruent RTs in the associated colour naming experiment.

Our main purpose in conducting these experiments was to examine whether the synesthetic Stroop effect is unique to synesthetes. This was achieved by making methodological improvements to the paradigm and investigating the data that resulted from these improvements. The overall experimental finding - that synesthetes and controls cannot be differentiated in either experiment - points to a conclusion that the synesthetic Stoop test is simply testing the strength or consistency of learned or associated stimulus parings.

The Stroop paradigm however, may still have a contribution to make to synesthesia research because several more methodological improvements and other variations of the testing design can be made. We cannot yet explain why for example, the synesthetic Stroop interference effect is enhanced in synesthetes by using opponent colours in an incongruent condition (Nikolic, Lichti, & Singer, 2007), suggesting that early visual system processes may influence the effect. This will need to be investigated in future. By using unique stimulus ensembles, we may be able to tease out the perceptual elements in the synesthetic Stroop paradigm, particularly if these effects are only seen in idiopathic synesthetes and not in controls.

Along with the idea above, we suggest investigating the following design changes for future investigations of the synesthetic Stroop effect: First, a comparison of the effects of a balanced covariance matrix with a positively correlated matrix could be conducted, because the influence on synesthetes and controls may differ depending on the level of expectation created by the stimuli. Second, investigating the influence of different types of neutral conditions interspersed in the colour naming experiment design may be useful, because neutral conditions may not be neutral at all and require some evaluation (Roelofs, van Turennout, & Coles, 2006). For example, 5 different stimuli could be used instead of a single tilde, and graphemes with 'no colour' associations could be used in the associated colour naming experiment. Third, further investigation and replication of the time course of facilitation, interference and congruity effects seen in our experiment are warranted to tease out why, synesthetes show different time course effects in facilitation and interference than controls.

In short, it appears likely that the synesthetic Stroop effects seen in previous experiments may be the result of semantic level associations common to both synesthetes and non-synesthetes and that the overall synesthetic Stroop effect is not a diagnostic marker of synesthesia, at least in the way it has been purported previously.

5. WHAT DO MULTIPLE CONCURRENTS OR POLY MODAL CASES OF SYNESTHESIA TEACH US ABOUT THE CONDITION: TWO CASES

5.1. Introduction

In Chapter 1 it was explained that about half of the self-referred synesthetes surveyed by Day (2005) report they have multiple forms of synesthesia. For example, a person reporting synesthetic colours for words might also report synesthetic colours for music or smell. Less frequently however – and there is no incidence data on this aspect – it is reported that the same inducing stimulus induces a range of synesthetic concurrents. Letters for example, may have colour and personality. From the lack of attention such synesthesias are given in the literature one could easily and mistakenly conclude that all synesthesias were one inducer to one concurrent relations, rather than a one to many phenomenon.

One of the earliest documented cases of poly-modal synesthesia was described in 1968 by Luria and Solotaroff (1987). A Russian male 'S' with a mnemonic memory also described synesthetic experiences with heard sounds and other inducers. When presented with a noise at 200 cycles per second, S reported that he saw "something like fireworks tinged with a pink-red hue. The strip of colour feels rough and unpleasant and has an ugly taste, rather like that of a briny prickle... you could hurt your hand on this". Recently published research on poly-modal synesthesia include two studies of the synesthete ES who experiences interval-taste and tone-colour synesthesia (Beeli, Esslen, & Jancke, 2005; Hanggi, Beeli, Oechslin, & Jancke, 2008). There are also a small number of multi-concurrent studies which investigate ordinal linguistic personification which occur with colour (Simner & Holenstein, 2007). One aspect that is often reported in coloured hearing (say for music) or grapheme-colour synesthesia, is that form or shapes are reported as concurrents (Ward, Huckstep et al., 2006). This aspect of the experience has been neglected for study in the past but is an important attribute of the experiences of many synesthetes. Form or shapes can be an integral component of the synesthetic experience. Grapheme shapes and geometric shapes can induce coloured synesthesia and geometric or other shape forms are also reported as concurrents. This implies a central role for form perception in synesthesia. Consider colour, the most common feature for examination of synesthesia and often considered to be its most central characteristic. Colour, unlike form, is rarely reported as an inducer of synesthesia. The current fascination with colour concurrents in grapheme synesthesias may have obscured another facet of the condition; that form plays a central role in defining broader aspects of the phenomenon.

In the current research literature, shape as a concurrent with colour is mainly presented as case descriptions and the mapping of inducer - concurrent pairs are described (Cytowic & Wood, 1982). The most notable case was described by Cytowic (1993) who studied a synesthetic male who tasted shapes when tasting flavours or ingesting food. Attempts to map the concurrent shape experiences of synesthesia include work with synesthete MW (Cytowic & Wood, 1982) and work with synesthete GS (Mills, Boteler, & Larcomb, 2003). Both studies reported that the responses of the synesthetes were restricted. Only a few possible shape types were reported for a wide range of inducing stimuli. Beyond simple classification of shape type (for example, pointed, cube) a more expansive taxonomy for classifying aspects of the phenomenology of concurrent shapes in synesthesia has not been developed. Induced synesthesias on the other hand, such as those reported by Kluver (cited in Betancourt, (2007) and synesthetic correspondences between sense modalities (inter-sensory translations) have been subject to more rigorous scrutiny and universal principles underlying them have been found (Marks, 1987; Melara, 1989). Apart from the observation that graphemes have elementary shape properties (Alvarez & Robertson, 2009), there is no previous research on other types of shapes as inducers of synesthesia. Moreover, the geometric shape-to-colour synesthesia reported in the previous chapter, does not appear in Day's (2005) otherwise comprehensive list of inducer – concurrent pairs.

In this chapter two cases of synesthesia, in which the individuals report multiple concurrents, are discussed. In one case, synesthesia is reported only for auditory stimuli such as music and sounds. In the second case, a more elaborate set of inducers evokes a wide range of synesthetic concurrents. Both report shape and colour concurrents to sound stimuli.

If we are to understand synesthesia fully, then we must give attention to the cases which extend the commonly studied variants and challenge existing theoretical accounts. In depth examination of the characteristics of complex cases must be attempted and the implications of these for theory must be inferred. The work presented in this chapter was mainly exploratory and descriptive. It describes only two of the many poly-modal and multi-concurrent synesthetes who provided data for the studies in this thesis. The shape concurrents induced when listening to music for the

Australian artist Steve Glass, and the shape and other concurrents induced by graphemes, music, sounds and emotions for participant EL, are examined. Several questions are of interest. First, we focus on the shape/form aspects of the concurrents and ask whether the concurrent shapes experienced by both these participants can be considered to have any defining characteristics and whether the overall organisation of shape in the synesthetic experience may be systematic. The experiences of EL are further described in terms of the multiple concurrents experienced and how they might relate to one another. In this chapter we attempt to do no more than to describe the two cases, point out the phenomenological characteristics that they have in common by way of a simple cross-case comparison and ask what these cases might tell us about synesthesia. We point out the ways in which they demonstrate the limitations of the most popular explanation of synesthesia, the local cross linkage hypothesis and recommendations for further study are made.

5.2. Case 1

5.2.1. Shape and Colour Concurrents in the Synesthesia of Steve Glass

Steve Glass is a respected and prolific Australian artist. He reports projected synesthesia for music and other environmental sounds. Steve became aware of his synesthesia for music at about the age of 18 when listening to music in the dark. He has infrequent occurrences of synesthesia in full light, but reports that very loud environmental sounds, such as unexpected construction noises or ambulance sirens may elicit strong colours and rectangular shapes under these conditions. These attract his attention automatically and can be all consuming. For example, he makes the following interesting comment "in loud environments such as nightclubs, the visual stimuli get too loud, Oops, the visual stimuli from the loud noise get too bright". This suggests a contrast effect for his synesthesia which has been reported for other synesthetes previously (Hubbard, Manohar, & Ramachandran, 2006). In this case, the darker the environment, the stronger the perceived synesthesia. The spatial location of the projected synesthesia occurs in the direction where the sound is generated. For example, the projected image created by a moving siren from an overtaking ambulance is seen on the right hand side and stays in its originally projected location when his head moves. All his synesthetic experiences for music and sound involve the elicitation of the same rectangular shape but variations in colour, size and saturation occur.

Steve Glass provided electronic photographs of his artwork for our examination. The photographs presented in this chapter are of paintings he made specifically to represent his synesthesia directly, except for the painting entitled 'Sour Times' which he describes as a more artistic than realistic rendition of his synesthetic experience. These works were made by the artist prior to this study and outside the scope of it. This production was therefore not influenced by any expectations of the researcher or research inquiry.

The first piece of work to be examined is titled 'All pianos are Blue' (Figure 5-1). This work was inspired from the musical piece entitled La Valse D'Amelie, (piano version) from the soundtrack of the film Amelie. The art represents about one second's duration of the music. The second piece (Figure 5-2), is titled 'Penguins & Polar Bears' which takes its name from the song which inspired it, by the band Millencolin.

Figure 5-1

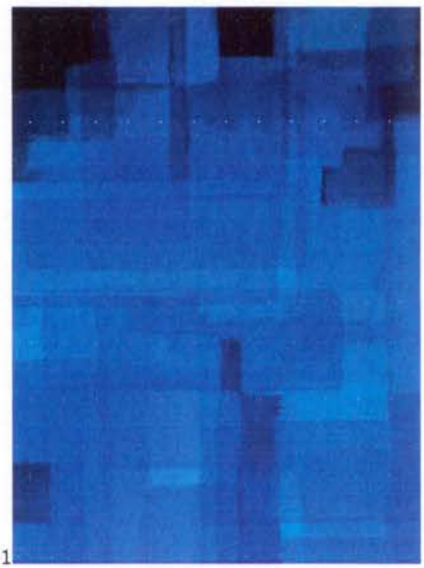

Figure 5-2

Figure 5-1. Artistic work entitled 'All Pianos are Blue' © Steve Glass
Figure 5-2. Artistic work 'Penguins & Polar Bears' © Steve Glass

In the two artworks colour is category specific. Pianos are blue. Steve reports that the blue hue differs slightly for different pianos but he has never heard a piano of any other colour. Figure 5-2 shows that a different colour is painted for each musical instrument in the song and also for the singer's voice. It is difficult to see in this reproduction but the writing in the original – which is a copy of some lyrics – is in a deep purple colour; the reported colour of the singer's voice. Red is the colour Steve perceives for the guitars in the music and black is seen for drums.

The works have structural symmetry both because of the presence of rectangles and also due to the repetition of the rectangles. The rectangles are filled, not outlined. The colour is a property of the shapes and bounded by it. One interesting attribute that the works show is the strong repetition of the shapes. Each repetition is based on a single inducing stimulus. There is a field of rectangles for each note which come and go as each note fades. This occurs for each instrument that produces a sound. There is no overall organisation of the shapes based on sound properties in the visual field. For example, low notes are not in the lower field. The field of notes are quite bright once played and fade to black as the note diminishes in volume. Lightness to pitch correspondences occur but higher notes which are inherently brighter do not take longer to form or dissipate than the lower (darker) notes. Brightness variation with pitch has previously been shown for both synesthetes (Ward, Huckstep et al., 2006) and controls (Marks, 1989) and therefore does not make this aspect of the experience distinctive of synesthesia. The initial luminance of the rectangle is brighter in the direction from which a sound is coming. It also varies depending on the duration of the note. There is a direct relationship between the strength of the sound and the strength of the synesthesia perceived. There does not appear to be strong surface texture effects in the work or his experience that are not derived from changes in luminosity. Steve reports that while music doesn't usually have a lot of different texture, when the sounds of guitars or other instruments are distorted the edges of the shapes are a little rougher.

There is motion in the experience as a whole, but motion of the concurrent rectangles does not occur. Projected single images are held in their original location despite any head movement which may be made. Thus once projected the synesthesia does not have the same phenomenology as imagery which occurs in the mind's eye and moves in the mind with head movement. The perceived synesthesia operates as if it was a perceived object in the external environment. Once the concurrent rectangle appears it does not change location. Form concurrents in that respect are static. Synesthesia for each note occurs in the participant's field of view and occupies peri-personal space, approximately fifteen centimetres (six inches) away from the participant's face/body. This is illustrated in Figure 5-4 and discussed below.

Many artists have explored synesthesia (Van Campen, 1999) and many synesthetes explore art (Rich et al., 2005), so it is important to distinguish a literal representation from an artistic one. A contemporary piece of work with more artistic license in its construction is presented in Figure 5-3.

Figure 5-3. Artistic work 'Sour Times' © Steve Glass

This piece crosses the line between realistic representation and art. The title of the piece is taken from the song 'Sour Times' by the band Portished that induced the original experience of synesthesia. The artist reports that several factors and many decisions are involved in how to make the representation from his momentary experiences. Represented in the artwork also are the singer's voice, the cowbell (in red) played in the piece, and other percussion instruments. The light teardrop shape in the work is not part of his synesthetic experience but is an artistic expression. The work shares many aspects of its construction with the works that are literal interpretations of Steve's experience.

A final work is shown in Figure 5-4. The work illustrates the projected nature of Steve's synesthesia. It is an actual light projection of another artwork onto a piece of fabric. The artist is shown standing in front of the work – about 6 inches from the fabric. It is a position where the piece occupies his whole field of view. The sizes of the rectangular shapes are approximately the same as they occur in his synesthetic experience when viewed from this position. The only improvement he would make to complete its realism is to have the fabric enclose him in a circular shape.

Figure 5-4. Photograph of Artist in situ with a representation of musical experience from a self composition © Steve Glass

It is evident that there is more to the experience of synesthetic shape concurrents than the presence of simple geometric form emphasised in earlier studies. Much broader aspects of the phenomenology have been made obvious. It is clear from this case that the shape concurrents experienced in synesthesia have a variety of features other than simple geometry by which they can be described. In particular symmetry, repetition, and motion are features not previously considered systematically in the literature and could be investigated by researchers in future.

5.3. Case 2

5.3.1. The Multiple Concurrents in the Synesthesia of EL

EL is a 23 year-old female synesthete. She reports being aware of her synesthesia since childhood. She is not aware of other family members having synesthesia. EL reports multiple synesthetic inducers which include graphemes, sounds, music and emotions. Multiple concurrents include colour, personality, gender, texture and shape. Her GCAT score was 0.565, well below the Type I recommended diagnostic score set in Chapter 2. She reports synesthesia mainly in her mind's eye. Some synesthesias induced by emotions are seen "on a screen in front of my head" or felt in her body and might be normally considered as 'projected' by researchers. However, EL is explicit they do not occur in the external world. EL provided broad ranging descriptions of her synesthetic inducer and concurrent pairings and a sub-set of illustrations for many of them. She made these illustrations using MS paint, outside of the laboratory environment. Tables of descriptions of each concurrent experienced for several classes of synesthetic inducers appears in Appendix G.

Illustrations of her colour, texture and form concurrents[16] for the numbers 0 to 9 are shown in Figure 5-5. Simple prototypes are evident and appear to be conceptually and orthographically related to the number, though this is not always the case. The number 3 is represented by triangles. EL describes these as "curved and fuzzy bumps". The number 4 is described by EL as a "long glass cylinder extending infinitely upward". This appears to be indicated by the orthographic shape of the number. The number 7 is represented by pairs of lines joining in a centre angle. The number 8 is represented by filled round shapes. The numbers 6 and 9 share curvature.

Shape concurrents in EL's number experiences are elementary and specific but show signs of both conceptual categorisation (3) and orthographic similarity (7, 8). Each number has an concurrent texture, gender and personality. Textures are evident in the illustrations but the illustrations do not portray the experience completely. For example, zero is described as translucent, three is described as soft, furry, little bumps like a dust cloth, but is also cheerful, silly and warm hearted and warm in temperature. 4 is sharp, glassy translucent, cold, rational and stern. The numbers 3,5,6,9 are female, zero is neutral and the other numbers 1,2,4,7,8 are male.

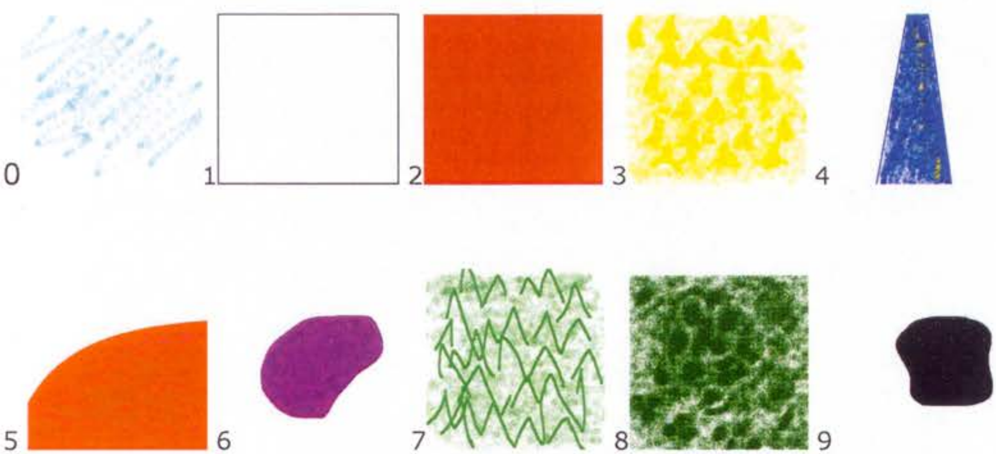

Figure 5-5. Illustrations of EL's colour and form concurrents for numbers 0-9

Shapes, textures and colour are concurrents for other synesthetic inducers. Figure 5-6 shows the illustrations made by EL for her synesthetic experiences of environmental

[16] Appendix G lists a range of concurrents including personality, gender and temperature, experienced by EL for numbers

sounds[17]. Many illustrations show some physical similarity to the events themselves, for example the depiction of fireworks which EL reports as separate experiences dissociable to the different sounds when hearing firework events. Others are not so obvious. In the first diagram for example, EL reports that chirping birds cause experiences of triangular shapes which have motion and bounce off one another. Textures are present and are variously described as rough for sawing, screeching tyres, waterfall and wind but doorbells and the whinny of a horse are smooth. Car horns, dogs barking and screams are sharp. EL describes the textures as; "it's as if you could touch it but I don't feel it in my hands".

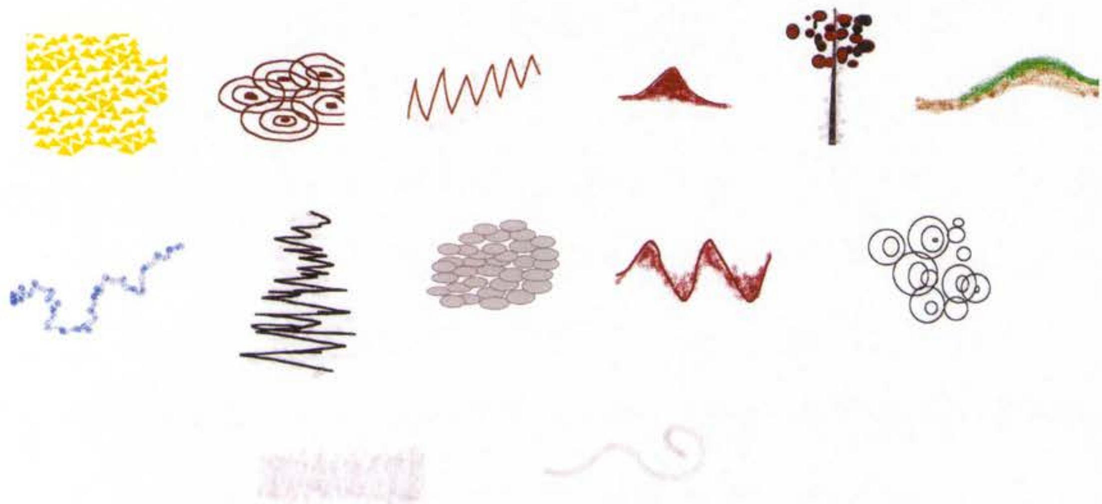

Figure 5-6. Illustrations of EL's colour and form concurrents of environmental sounds. From left to right: Birds chirping, airplane, sawing, car horn, fireworks, horse, sheep, screeching tyre, applause, ambulance siren, thunder, waterfall, wind

Figure 5-7 shows the illustrations provided by EL for emotions[18]. Colour choices of red for anger and green for jealousy seem likely to have arisen from conceptual sources, but the form illustrations are more difficult to explain. They appear to incorporate motion and texture. For example, calmness is experienced as "pale yellow, like sand dunes, with lots of little bits moving slowly together". Guilt is "small dark round blobs which float in a thick green liquid, the blobs are three dimensional, curved like blood cells; liquid is thick and gluggy". Several emotions are felt to be located in various parts of EL's body. For example, loneliness is felt "in front, on my body; I feel as if I could hold onto it in my hand and could choose to let go or snap it".

[17] Appendix G lists the other concurrents including texture and temperature experienced by EL for sounds
[18] Appendix G lists the other concurrents including temperature, texture and location experienced by EL for emotions.

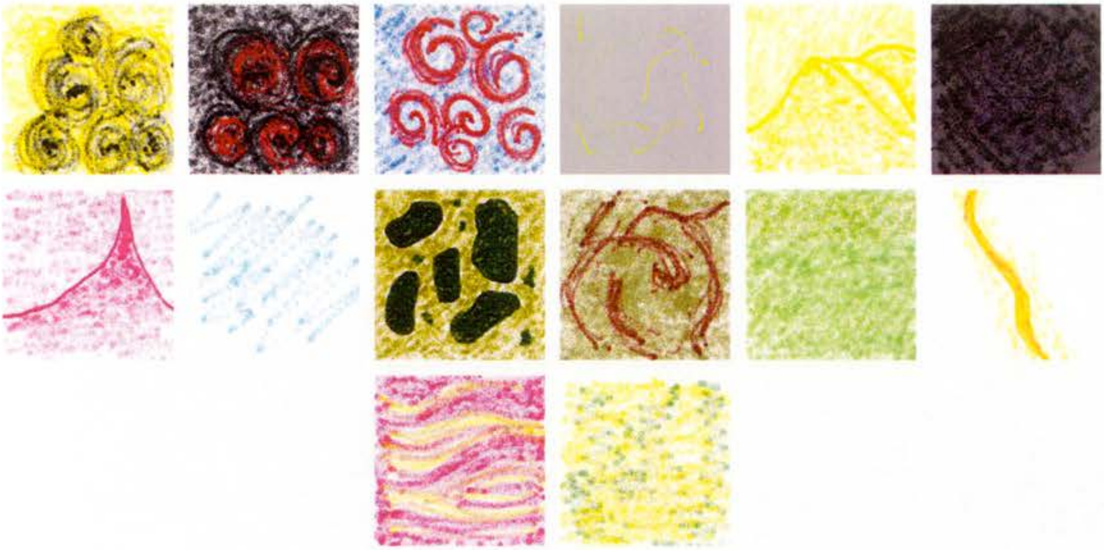

Figure 5-7. Illustrations of EL's colour and form concurrents of emotion: From left to right: agitation, anger, anxiety, boredom, calmness, depression, ecstasy, emptiness/zero, guilt, horror, jealousy, loneliness, pleasure, sadness

In Figure 2-43, EL's four drawings of shape concurrents for music[19] were presented. Pianos are represented by filled rectangles and string instruments by differently coloured wavy lines, similar to vibrating strings. There are multiple colours for each instrument. For example organs can be orange, pink or green.

So what can we discern from EL's multiple concurrents? With regard to shape or form, unlike the paintings presented earlier, symmetry is present in individual aspects of the illustrations as basic geometric shapes of triangles and circles. The forms do not have a consistent sense of repetition although it is present in many diagrams and particularly those which fill the whole illustration. On the whole, repetition of the shapes appears to be a variable feature of EL's synesthesia, and is strongest in the synesthesia induced by numbers. Shapes are relatively elementary and are not elaborated (such as pictures of complex scenes for example). In some designs there is strong curvature and others are fully linear but in general shapes are filled. EL's experiences overall do not appear to have very sharp edges, even when angular. Unlike the specific representations of Steve Glass, there is not an apparent or reported method to changes in brightness between different representations. EL does report that some synesthesias are stronger than others however, and these appear to her to have more saturation. For example, there is a great deal less saturation in the experience of boredom.

[19] Appendix G lists the multiple concurrents for a range of musical instrument inducers.

EL's concurrents have texture and temperature. The texture and temperature of EL's synesthetic concurrents is expressed in elementary ways. Rough, smooth, sharp and spiky are common descriptive terms as are cold, cool and warm. The vast majority of her experiences that are described as weak are often translucent, light, fluffy or woolly though not exclusively so.

EL's synesthetic concurrents have a specific location in space but EL reports a varied experience of locations. She describes the experience as follows: "if I ask myself *where* the image is, sometimes it is a 3D image in my head, and at other times it is located on a screen in front of my eyes. But this is just the *location*, it doesn't mean that I actually see it there". This description suggests the simple dichotomy of projected vs. mind's eye may be an insufficient classification system. It seems possible to have an experience of projection within a mind's eye experience. Spatial location or 'spatial extension' (Cytowic & Eagleman, 2009) may be the more accurate terminology or general conceptualisation. The limited utility of the projector-associator distinction has also been made previously by Ward, Li, Salih, & Sagiv (2007) who suggest a stronger classification scheme based the disambiguating the spatial frames of reference described by a synesthete. In this classification scheme, EL would be considered a 'see-associator'. However, her experiences might be difficult to accurately classify as she also describes sensations in her body and uses terms that imply projected concurrents. This suggests that even with improvements in this aspect of the taxonomy of synesthesia, the various characteristics related to spatial reference may not be mutually exclusive.

EL's synesthetic concurrents are often in motion. Motion is also implied in many of the illustrations of her synesthesia. There are instances of the synesthetic concurrent itself being in motion such as chirping birds giving a synesthetic experience of triangles bumping together. The illustrations themselves do not demonstrate where the synesthesia is experienced.

Aspects of EL's synesthetic concurrents are metaphorically sensible. Red for anger, being tied up in knots; green for jealousy; and the angular back and forward motion of a saw, for example. It is likely they represent a more semantically based inducing mechanism in the synesthesia of EL, all the more interesting because her multiple synesthesias are pervasive, and generally not projected. This is mainly consistent with the conclusion of Ramachandran et al., (2002) that semantically based synesthesias are produced by higher synesthetes and are not projected.

EL's synesthesias also further support the assertion of Marks (1982) and Ramachandran (2004) that metaphors have their basis in synesthesia and have much in common with it. The illustrations could also be considered as clear examples of metaphorical thinking. Indeed, if it were not for the fact that they are literal representations of EL's actual perceptual experience, they might be considered as such. We trialled whether these illustrations could be directly interpreted by a non-synesthetes by giving the full set of illustrations and a list of picture names for each category to an individual not associated with the study. We asked her to match each diagram with a member of the list. The individual had little difficulty in matching the verbal label with the correct diagram. Of course, this is only one instance, but it does indicate the ease by which synesthesia and metaphor can be related. An interesting future project might be have a large control group undertake the same task. It would be expected this would give a similar result and one which would be consistent with the demonstration by Ramachandran and Hubbard (2001a) that the words 'kiki' and 'bouba' are intrinsically understood and applied consistently to specific visual shapes.

5.4. General Discussion

In this chapter we have mainly focussed on the presence of shape concurrents in synesthesia and described their characteristics in relation to both cases. The shape concurrents in idiopathic synesthesia can be consistent with the simple form constants originally described by Kluver (Betancourt, 2007). The Taxonomy of Abstract Forms (Betancourt, 2007) which was developed from the observations of drug induced synesthesia and cross-modal correspondences, was instructive in our exploration of the phenomenology of shape in these case reports of idiopathic synesthesia.

When comparing these two cases we are able to see some trends in relation to the presence of shape concurrents which may be instructive. First, there are distinctive elements in shape concurrents. Repetition and symmetry are strong features. The fields of rectangles seen by Steve Glass and spiral shapes felt by EL are repeated. Why this should be the case, warrants further investigation. There is some similarity with the kind of phenomenology which occurs with Charles Bonnet syndrome, in which the repetition of images across the visual field is often reported (Ball, 1991). This is however, where the similarity ends as there is no visual system damage or loss that co-occurs with idiopathic synesthesia, nor was reported with either individual. Shapes are distinctive, rather than being unformed or low level. Curvature seems emphasised over angularity in these cases. Even when angular or pointed, shapes tend not to have completely sharp edges. In most cases colour is bound to the shape reported and shapes are filled, the boundaries of the shape being defined by the cessation of colour rather then any distinctive outline.

Second, there are both sensory effects and conceptual effects. Contrast effects are seen. It was also found that the shape concurrents are influenced by other synesthetic principles, such as lightness to pitch, some of which have been shown to be present in all individuals (Marks, 1989) and support the suggestion of a common basis. At the very least they suggest that synesthetic processing is not derived from special pathways but travels through the same processing hierarchy as normal perception even when there is more than one concurrent for each inducer. Further, the form concurrents in synesthesia induced by numbers, sounds and emotions, in EL, can have obvious conceptual influences suggesting that the links between metaphor and perception may be closer in some individuals and some synesthesias.

Finally, motion has a role in the form concurrents in synesthesia, even though it does not appear to be consistently paired with form. Motion is particularly salient with inducers which imply motion, the sound of music, not simply static notes, and the sound of birds chirping for example, but is not restricted to these; the letter L being "fluid like an egg white" (EL).

The presence of motion in addition to texture in the form concurrents of synesthesia may require an expansion of the assertion that texture effects imply much larger areas of the ventral visual stream may be involved in synesthesia (Eagleman & Goodale, 2009). Motion effects in synesthetic concurrents as well as three dimensional locations of those concurrents suggests at an even broader spread of activation to the dorsal visual cortex, is likely in poly-modal or multi-concurrent synesthesia.

In summary, it is more likely that synesthesia is generalised both in the visual system and the areas to which it directly projects. Connectivity between the grapheme processing areas of the cortex and areas processing meaning and categorical information as well as areas defining location, shape and motion are implied by the presence of these multiple concurrents. Of course, it is well known that no two synesthetes experience the same things even if they are twins, such as JS and CS described in Chapter 2. There are however, common underlying aspects of the experience which may be shared across individual synesthetes. These are the presence or absence of texture, motion, shape and also whether these are projected or are typified by occurring in a specific location. By contrasting the neuroanatomy of synesthetes who have multiple concurrents (and sub-classification of the types of concurrents experienced), with those who have simple grapheme to colour synesthesias – using diffusion tensor imaging (DTI) or voxel based morphology (VBM) techniques for example - we may well be able to discern the extent to which synesthesia is a local or diffuse neuroanatomical phenomenon.

At present, we must be satisfied with the fact that these synesthesias are poorly explained by current accounts and thus suggest that the field is still a long way from a full account of poly-modal synesthesias and those which include multiple concurrents. The development of a library of such case accounts might be a helpful first step and may enable cross case comparisons.

6. SYNESTHESIA AND ABSORPTION

6.1. Introduction

In this chapter we investigate the relationship between synesthesia and the trait/state of absorption. In Chapter 4, we hypothesised that absorption might be involved in the reduction of interference in the concurrent colour naming synesthetic Stroop experiment.

Spontaneous synesthetic experiences are often reported as occurring under altered or absorbed meditative states (Walsh, 2005) and apparently differ from idiopathic synesthesias in terms of the attentional demands required to elicit them. However, they appear to have similar underlying phenomenology. Idiopathic synesthesias are however, can be synonymous with the types of spontaneous visual imagery reported in altered or absorbed states of consciousness such as hypnosis and meditation. Walsh (2005) for example, shows that meditators report synesthetic experiences more commonly than controls and that the descriptions of the experience can be qualitatively similar to those of idiopathic synesthetes. In Chapter 5 we described the geometric form and symmetry of Steve Glass' paintings (representing his music-colour synesthesia) and the synesthetic concurrents of EL. These illustrations have some consistency for example, with the simple geometric form constants induced by the drug mescaline, reported by Kluver cited in (Betancourt, 2007). Other, drug induced states, such as those occurring with the psychotropic brew Ayahuasca, have also been reported to have remarkable similarity to the synesthesia involving colour and music (Shanon, 2003). Simply put, spontaneous synesthesias and idiopathic synesthesias share some common underlying phenomenology with similar inter-sensory principles of translation but they do not seem to require the same attentional states to produce them.

In this chapter we discuss the family of synesthesia (idiopathic, inter-sensory translation ability and spontaneous) in the context of the trait/state of absorption. Recall from the introduction that we use the term 'spontaneous synesthesia' (Hunt, 2005) for those synesthesias which arise under the influence of altered or absorbed states of consciousness such as meditation and are not typically seen to be idiopathic or consistently elicited. We use the term controls to describe those without idiopathic synesthesia. We therefore leave open the question of the extent to which these 'non-synesthete' participants may demonstrate superior synesthetic inter-sensory translation ability or frequent spontaneous synesthesias.

Absorption is defined by as:

> *"Absorption is interpreted as a disposition for having episodes of "total" attention that fully engage one's representational (i.e., perceptual, enactive, imaginative, and ideational) resources. This kind of attentional functioning is believed to result in a heightened sense of the reality of the attentional object, imperviousness to distracting events, and an altered sense of reality in general, including an empathically altered sense of self."* (Tellegen & Atkinson, 1974)

The concept of absorption has been examined with hypnotic susceptibility (Tellegen & Atkinson, 1974), imagery ability (Hilgard, Sheehan, Monteiro, & Macdonald, 1981), imagery vividness (McConkey & Nogrady, 1986) as well as fantasy proneness (Hunt, Dougan, Grant, & House, 2002). Absorption is usually a positive trait/state but it is not always the case, as it is weakly related to hypochondriacal concern (McClure & Lilienfeld, 2002).

Synesthesia has always been a component of the factor structure of the Tellegen Absorption scale (TAS), the most widely utilised measure of absorption (Tellegen & Atkinson, 1974). In developing the absorption scale and elaborating on its content features, Tellegen (1981) asserted that "some absorption episodes have a synesthetic quality" and this appears to be a consistently reported aspect of the phenomenological reports of those under the influence of drugs or engaged in meditation. A recent study of participants with high imaginative absorption were assessed for reporting of childhood synesthesias and altered states of consciousness against a range of personality and other measures including absorption (Novoa & Hunt, 2009). Absorption was found to be the only significant predictor of recalled childhood synesthesias in the study.

Tellegen's (1981) work may be unfamiliar to the reader so we offer the following short summary of the suppositions made about those with high and low absorption capacity and how this might relate to our data. There are "two hypothetical temporary mental sets or states: an experiential (or respondent) set and an instrumental (or operant) set. The experiential set is a state of being open to experience - the "readiness to undergo whatever experiential events, sensory or imaginal, that may occur, with a tendency to dwell on, rather than go beyond, the experiences themselves and the objects they represent" (Tellegen, 1981). These experiences are effortless and involuntary. They are correlated with high absorption. An instrumental set, on the other hand, is defined as "a state of readiness to engage in active, realistic, voluntary, and relatively effortful planning, decision making, and goal directed behaviour". Sensory input is used to distinguish stimuli and guide its instrumental use. These are correlated with low absorption. "High-absorption, compared to low-absorption, individuals are more ready and able if circumstances permit, to adopt an experiential set, whereas low-absorption individuals are more likely to adopt an instrumental set" (Tellegen, 1981).

Idiopathic synesthetes report that absorbed or focused states of attention are important influences in the experience. 46% of synesthetes sampled reported that attention could increase the vividness of their synesthesia (Rich et al., 2005). Synesthetes in our sample, reported that their synesthetic experiences were stronger when they were relaxed but also when they were attended to, that synesthetic experiences drew attentional resources because they were engaging, and that they provided advantages to memory. Further, the experience is not preconscious or unconsciously elicited and attention to the inducing stimulus is required for the experience (Rich & Mattingley, 2010). On balance, it appears, at least for grapheme-colour synesthesia, the inducer must be identified, either by its graphemic form or its context in language. However, the extent to which attention is required for both idiopathic and spontaneous synesthesia, the types of attention which need to be applied to induce the experience and an individual's capacity for focussed attention are not yet understood.

Synesthesia and absorption may share a similar pharmacological basis. Two pieces of evidence are supportive of this assertion. First, there is a biological basis for absorption. An investigation of the 5HT2a gene and the trait of absorption was undertaken by Ott, Reuter, Hennig, & Vaitl (2005). It was found that there was a strong correlation between high absorption scores and the T/T genotype of the T102C polymorphism. Thus those with a stronger binding potential on the 5HT2a receptor would be more likely to report absorption in everyday activities. Moreover there was a significant interaction between this gene and the COMT gene suggesting some interplay with dopaminergic systems. The 5HT2a gene is implicated in the activity of LSD (Egan, Herrick-Davis, Miller, Glennon, & Teitler, 1998) and schizophrenia and other major mental illnesses (Ucok, Alpsan, Cakir, & Saruhan-Direskeneli, 2007). Second, Brang & Ramachandran (2008) recently postulated that the S2a gene is implicated in synesthesia. They cite the following reasons as suggestive of a pharmacological basis of synesthesia: First, that there is similarity between synesthesia and experiences produced by LSD. Second, that there are reports of synesthesia being inhibited by Prozac (increasing the level of serotonin and thus the inhibition of S2a). Finally, and more impressively they report a (number form) synesthete who after ingesting melatonin experienced colours for letters (all blue but different shades).

6.2. Aims and Hypotheses

A capacity for absorption may be necessary (but not sufficient) for the spontaneous synesthetic experience. An assessment of the trait of absorption may be as helpful in the examination of idiopathic synesthesia as it has been for spontaneous synesthesias or those with strong inter-sensory translation skill (Rader & Tellegen, 1987; Rader, 1980; Rader & Tellegen, 1981). Novoa & Hunt (2009) suggest that there is a broader continuum of synesthesias of which idiopathic synesthesia is only "the iceberg's tip". A preliminary study of absorption within both idiopathic synesthetes and controls may therefore bring us one step closer to uniting the literature between the "strong and weak" forms of synesthesia (Martino & Marks, 2001) and discussed by Glicksohn, Salinger, & Roychman, (1992). The primary motivation for our questions is the claim by Glicksohn et al., (1999) that high absorbers are likely to be synesthetes. Since our investigation is preliminary, we seek to confirm the question: are synesthetes more able or willing than controls to have "episodes of "total" attention that fully engage (their) representational (i.e., perceptual, enactive, imaginative, and ideational) resources?" (Tellegen & Atkinson, 1974). The working hypothesis is that idiopathic synesthetes will report higher levels of absorption than the control groups. Since we have collected absorption data from all the participants in the experiments presented in this thesis, we also opportunistically cross-examine the relationships between the GCAT, Stroop effects and absorption.

6.3. Method

To investigate this question we utilised The Modified Tellegen Absorption Scale (MODTAS) (Jamieson, 2005). The MODTAS is an updated version of the original Tellegen Absorption Scale (Tellegen & Atkinson, 1974) which utilises a 5 point likert scale replacing the original yes/no response.

6.3.1. Participants

The MODTAS was administered to two groups of control participants (N = 617 and N = 126) and one group of grapheme-colour synesthetes (N = 29).

For the first control group the MODTAS was administered as part of a mass screening protocol using first year psychology students. All participants received course credit for participation.

For the second control group the MODTAS was routinely administered to participants undertaking synesthesia-related research and specifically those who participated in the testing in Chapters 2, 4 and 7). These participants were either volunteers, reimbursed $20 per hour of testing or received course credit for their time involved.

All participants gave informed consent and the study was approved by the Human Research Ethics Committee of the University of Sydney.

6.3.2. Questionnaire Administration

The MODTAS questionnaire (Appendix A) was administered as paper and pencil tests and took approximately 4 minutes to complete. Basic demographic data was collected. Coding of questionnaires was undertaken using MS Excel and SPSS.

6.3.3. Method of analysis

A missing value analysis (MVA) using the estimated means (EM) method was undertaken to estimate any missing values in the questionnaire data. No missing value estimates were needed for synesthetes but a small number were required for the mass screening (MS) control group and the experimental control group. This method was conducted for each group separately. 4 of the 617 questionnaires collected from the MS control group were excluded as they had greater than 10 of the 34 questions unanswered (these participants skipped a page of questions) leaving a total sample size of 613. Scores for each of the subscales were derived from the formula described in study 2 of Jamieson (2005). All statistical processes described in this chapter were conducted with SPSS 15. A one-way analysis of variance was chosen to examine the data from the three samples. Post hoc tests use the Fishers LSD method.

6.4. Results

6.4.1. MODTAS Total

The MODTAS score represents a participant's total score on the scale in raw score terms. Synesthetes have a significantly larger mean MODTAS score (N = 29, M = 80.68, S.E. = 4.49) than the experimental control group (N = 126, M = 63.29, S.E. = 1.81) or the MS controls (N = 613, M = 61.89, S.E. = 0.90), $F(2,765) = 10.14$, $p < 0.001$ (Figure 6-1).

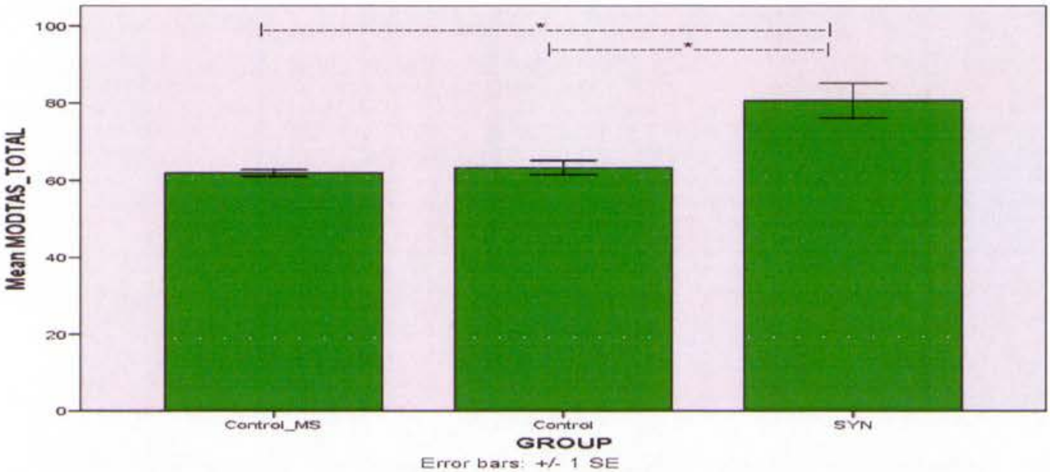

Figure 6-1. Mean and S.E. of MODTAS scores for mass screening controls (CONTROL_MS) experimental controls (CONTROL) and synesthetes (SYN). Error bars represent one S.E. of the mean. * indicates significant differences between the groups.

A priori multiple comparisons revealed that synesthetes have significantly greater scores on absorption than the experimental control group (mean difference 17.39, $p < 0.001$) and the MS controls (mean difference = 18.79, $p < 0.001$). The control groups are not significantly different to one another (mean difference = 1.40, $p = 0.516$).

Taking the MS control group as a population measure we derived a classification system for high and low absorption. Scores more than 1 SD higher than the MS control mean were defined as high absorbers. Scores more than 1 SD lower than the MS control mean were defined as low absorbers. No synesthetes scored in the low absorption range while 12.3% experimental controls did. 55.2% of synesthetes scored within 1 SD of the mean with the remaining scoring in the high range. 72.1% of the experimental controls scored within 1 SD but only 15.6% of the experimental controls scored more than 1 SD higher than the MS Control mean.

For conservativeness we also derived a MODTAS score after removing the synesthesia subscale and conducted an ANOVA between the groups. The effect did not change. Synesthetes still report a higher level of absorption in everyday activities (N = 29, M = 71.47, S.E. = 4.04) than both control groups (N = 131, M = 56.57, S.E. = 1.60) and (N = 613, M = 55.59, S.E. = 0.79) even without the benefit of the synesthesia items. $F(2,765) = 9.35$, $p < 0.001$.

While the data support our hypothesis that synesthetes in general report higher levels of absorption in everyday life, it is by no means explicit that all synesthetes are high absorbers. 27.3% fall below the mean of the MS control group. There were many high scorers on the TAS in the experimental group of which none were idiopathic synesthetes. However the highest scores (scores over 2SD above the MS control mean) did come from the synesthete group.

In short, synesthetes report higher levels of absorbed involvement in everyday activities.

6.4.2. Subscales

We examined each of the MODTAS subscales to discern whether there were any scales which may be significantly different between the groups.

6.4.2.1. Synesthesia

The synesthete group has a significantly larger mean Synesthesia subscale score (N = 29, M = 9.21, S.E. = 0.82) than the experimental control group (N = 126, M = 6.72, S.E. = 0.31) or the MS controls (N = 613, M = 6.30, S.E. = 0.152), ($F(2,765) = 8.65$, $p < 0.001$), (Figure 6-2).

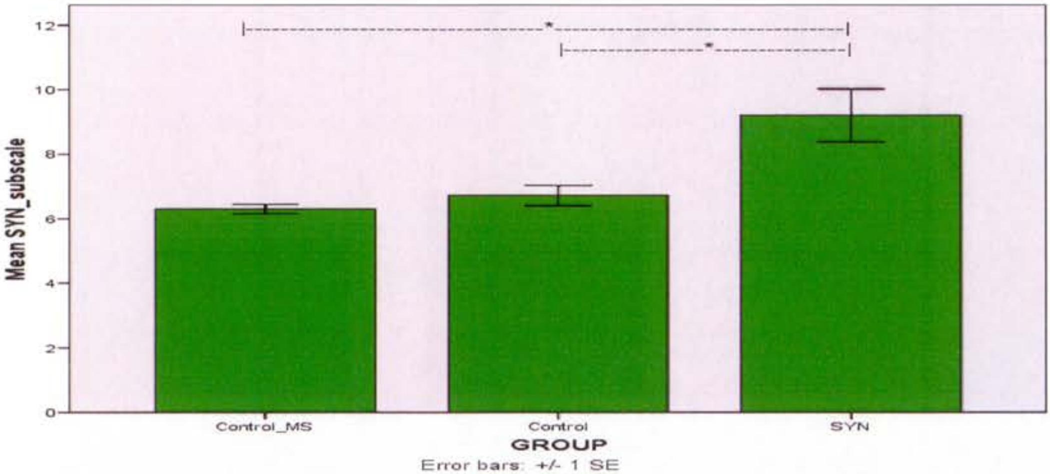

Figure 6-2. Mean and S.E. of Synesthesia subscale scores for mass screening controls (CONTROL_MS) experimental controls (CONTROL) and synesthetes (SYN). Error Bars Represent one S.E. of the mean. * indicates significant differences between groups

A priori multiple comparisons revealed that synesthetes have significantly greater scores on the Synesthesia subscale than the experimental control group (mean difference 2.49, p = 0.001) and the MS controls (mean difference = 2.91, $p < 0.001$). The control groups were not significantly different to one another (mean difference = 0.42, p = 0.25).

Interestingly the standard error of the synesthetes' scores was quite large. This possibly reflects the literal interpretation of some synesthetes to the items. It is entirely possible to be a genuine synesthete and have a very low score on the synesthesia subscale of the instrument. If you were a grapheme-colour synesthete and for example where, textures, music or odours do not elicit synesthetic colours, you might score low on these 3 items. High scores on this subscale therefore may be indicative of a spread of generalised synesthetic experience rather than a capacity or disposition toward a specific kind.

6.4.2.2. Altered States of Consciousness (ASC)

The synesthete group appears to have a significantly larger mean ASC subscale score (N = 29, M = 6.29, S.E. = 0.70) than the experimental control group (N = 126, M = 4.93, S.E. = 0.29) or the MS controls (N = 613, M = 4.58, S.E. = 0.14), ($F(2,765)$ = 3.833, p = 0.022), (Figure 6-3).

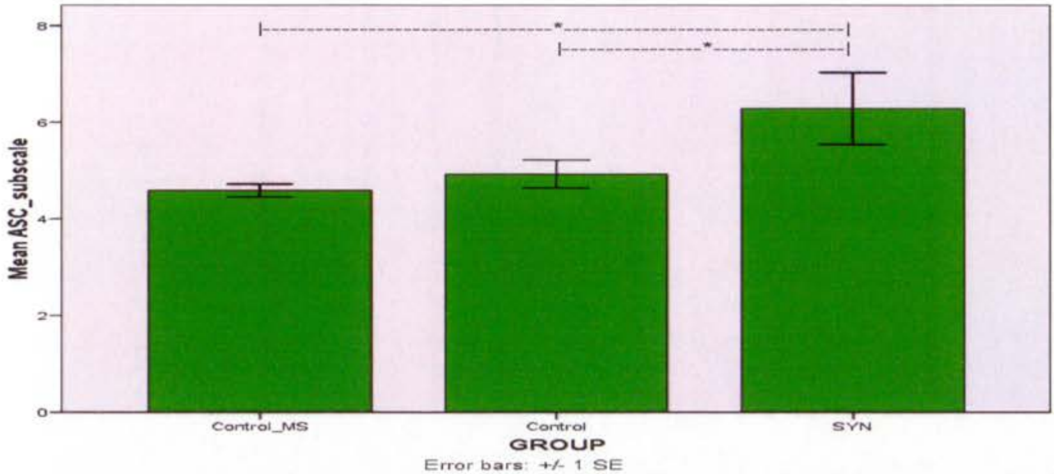

Figure 6-3. Mean and S.E. of ASC subscale scores for mass screening controls (CONTROL_MS) experimental controls (CONTROL) and synesthetes (SYN). Error Bars Represent one S.E. of the mean. * indicates significant differences between groups

A priori multiple comparisons revealed that synesthetes have larger (marginally significant) scores on the ASC subscale than the experimental control group (mean difference 1.36, $p = 0.051$), and the MS controls (mean difference = 1.70 $p = 0.008$ level). The control groups were not significantly different to one another (mean difference = 0.34, $p = 0.302$).

6.4.2.3. Aesthetic Involvement In Nature (AIN)

The synesthete group appears to have a significantly larger mean AIN subscale score (N = 29, M = 13.55, S.E. = 0.81 than the experimental control group (N = 126, M = 10.12, S.E. = 0.40) or the MS controls (N = 613, M = 10.32, S.E. = 0.18), ($F(2,765) = 7.65$, $p < 0.001$), (Figure 6-4).

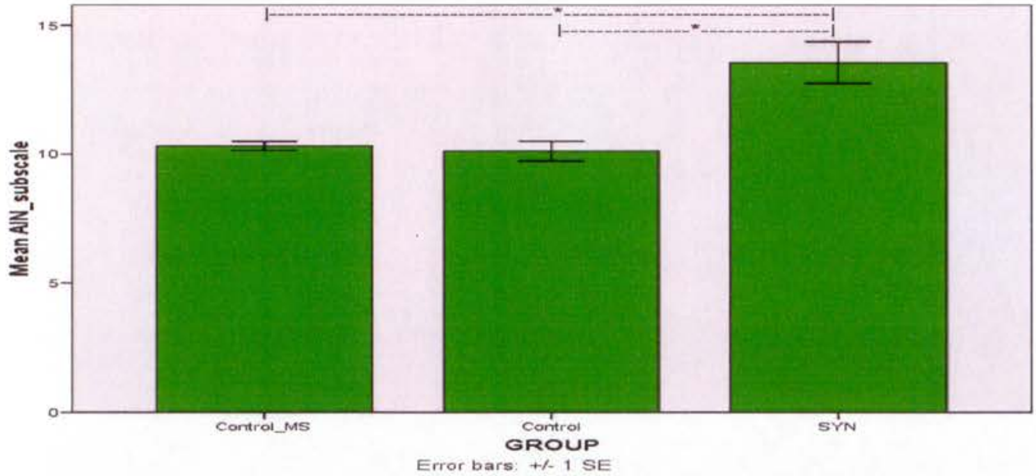

Figure 6-4. Mean and S.E. of AIN subscale scores for mass screening controls (CONTROL_MS) experimental controls (CONTROL) and synesthetes (SYN). Error Bars Represent one S.E. of the mean. * indicates significant differences between groups

A priori multiple comparisons revealed that synesthetes have significantly greater scores on the AIN subscale than our experimental control group (mean difference 3.43, $p < 0.001$) and the MS controls (mean difference = 3.24, $p < 0.001$). The control groups were not significantly different to one another (mean difference = -0.20, $p = 0.651$).

6.4.2.4. Imaginative Involvement (II)

The synesthete group appears to have a significantly larger mean II subscale score (N = 29, M = 23.90, S.E. = 1.23) than the experimental control group (N = 126, M = 19.33, S.E. = 0.52) or the MS controls (N = 613, M = 19.03, S.E. = 0.27), ($F(2,765) = 7.78$, $p < 0.001$), (Figure 6-5).

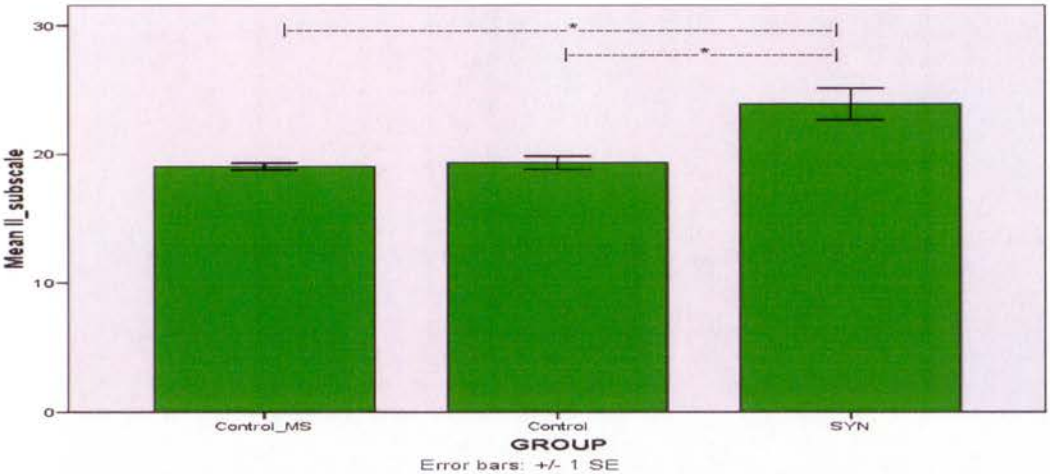

Figure 6-5. Mean and S.E. of II subscale scores for mass screening controls (CONTROL_MS) experimental controls (CONTROL) and synesthetes (SYN). Error Bars Represent one S.E. of the mean. * indicates significant differences between groups

Apriori multiple comparisons revealed that synesthetes have significantly greater scores on the II subscale than the experimental control group (mean difference 4.56, $p < 0.001$) and the MS controls (mean difference = 4.87, $p < 0.001$). The control groups were not significantly different to one another (mean difference = 0.303, $p = 0.633$).

6.4.2.5. ESP

The synesthete group does not have a significantly larger mean ESP subscale score (N = 29, M = 5.54, S.E. = 0.60) than the experimental control group (N = 126, M = 5.20, S.E. = 0.21) or the mass screening controls (N = 613, M = 4.82, S.E. = 0.11), ($F(2,765) = 1.905$, $p = 0.15$), Figure 6-6.

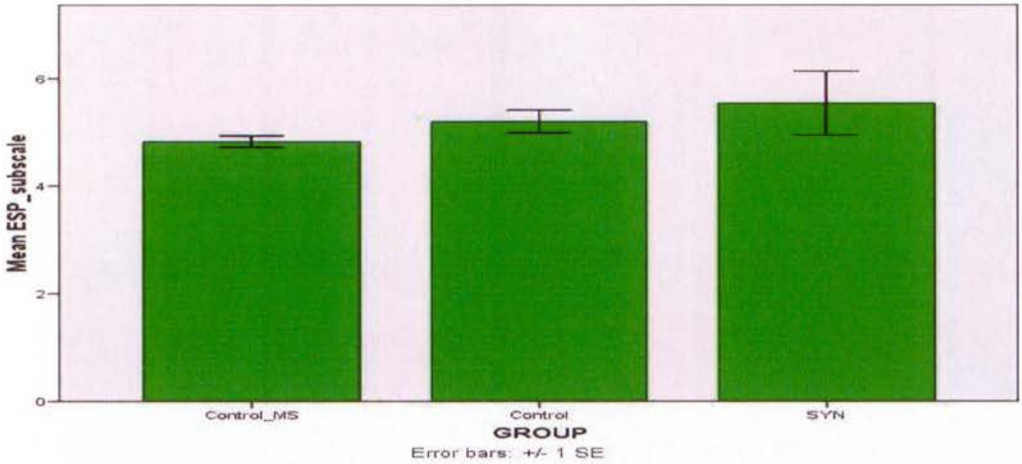

Figure 6-6. Mean and S.E. of ESP subscale scores for mass screening controls (CONTROL_MS) experimental controls (CONTROL) and synesthetes (SYN). Error Bars Represent one S.E. of the mean. * indicates significant differences between groups

6.4.2.6. Post Hoc Tests for GCAT, MCSAT, and SCSAT and Absorption

GCAT and GCAT shape colour

We examined the GCAT scores of both synesthetes and controls who participated in the experiments in Chapter 2 by conducting Pearson's correlations between MODTAS and GCAT for both groups. P values reflect two tail analysis and are uncorrected for the number of comparisons made.

There was no significant difference in the MODTAS scores between synesthetes (N = 20, M = 75.88, S.E. = 5.45) and controls (N = 19, M = 63.51, S.E. = 5.57), $t(37) = 1.55$, $p = 0.130$) who undertook the GCAT.

Synesthetes' GCAT colour match consistency score however is positively correlated with MODTAS such that high MODTAS scores are associated with high variability (inconsistency) (N = 29, R = 0.627, $p < 0.001$). This was not the case for controls where there was no relationship. (N = 104, r = 0.013, $p = 0.898$).

After removing our gendered colour and number synesthete (who did not report colours for letters), the total number of colour matches for orthographically similar graphemes was negatively related to the MODTAS score such that the higher the MODTAS score the fewer shape matches were made (N = 28, r = -0.414, $p = 0.028$)

(note from Chapter 2 that GCAT variability and shape matches are also negatively correlated). Interestingly this was true for same category matches (N = 28, r = 0.461, p = 0.014) and not for different category matches (N = 28, r = -0.237, p = 0.225).

For synesthetes, the synesthesia sub scale was related to the total number of colour matches for orthographically similar graphemes (N = 28, r = -0.566, p = 0.002) and both same category (N = 28, r = -0.505, p = 0.006) and different category matches (N = 28, r= -0.478, p = 0.01). We found no relationship between the MODTAS or the synesthesia subscale and the number of colour matches for orthographically similar graphemes for controls. (all p values > 0.05).

MCSAT, SCSAT

We assessed the relationship between the MCSAT and MODTAS and found a moderate and marginally significant suggestive positive correlation such that high variability correlated with high absorption score for synesthetes (N = 28, r = 0.341, p = 0.076 and not for controls (N = 51, r = 0.076, p = 0.597).

We found no relationship for the measures with the SCSAT for either group. (all p values > 0.05).

6.4.2.7. Post Hoc Tests of Stroop Effects and Absorption

Experiment 5 – Synesthetic Stroop screen colour naming

We examined the relationships between the derived measures of facilitation, interference or congruity and found no relationships between them and absorption or the synesthesia subscale.

Experiment 6 - Synesthetic Stroop associated colour naming

For the associated colour naming experiment we found no relationship between MODTAS and the response times of the congruity effect in the main experiment for either group. There was a moderate but not significant negative correlation between both the change in congruent response times and the change in incongruent response times and MODTAS (congruent change N = 19, r = -0.402, p = 0.088), (incongruent change N = 19, r = -0.393, p = 0.096) for synesthetes only. Low absorbers became faster across the experiment than high absorbers in both conditions.

With regard to the synesthesia subscale, again only for synesthetes, there was a strong and significant correlation with the congruency effect in the main experiment. Those who reported a high level of synesthesia in the MODTAS had a high level of difference in the response times between congruent and incongruent trials. (N = 19, r = 0.601, p = 0.006). Since we did not use a neutral condition in this experiment we cannot say with certainty that this was due to either facilitation or interference. However there was also a marginally significant relationship with the incongruent condition at the end of the experiment (N = 19, r = 0.449, p = 0.054), suggesting that high levels of reported synesthesia are correlated with slow incongruent response times at the end of the experiment. No such relationship was found for controls (all p values > 0.05).

6.5. General Discussion

Main results

We set out to examine the hypothesis that grapheme-colour synesthetes report higher levels of absorption in every day activities than controls. We found this to be supported by the significant analysis of variance between synesthetes and the two control groups. No synesthetes scored in the low range (which we have defined as 1 SD below the MS control mean). Further we have found that the Synesthesia subscale (and indeed all other subscales besides ESP) of the MODTAS is stronger in idiopathic synesthetes than in our control groups. This is the first time the scale has been used with a group of verified idiopathic synesthetes. Further, these results are contrasted with two quite different control groups: one population sample of 613 first year control participants (some of whom may experience synesthesia) and another group who participated in our synesthesia experiments who do not experience grapheme to colour, time unit to colour or sound/music colour synesthesia.

Consistent with the specific hypothesis of Glicksohn et al., (1999) we found that the most extreme scores on the MODTAS were those of synesthetes. However, we do not believe that the MODTAS is useful as a simple screening tool for synesthesia as several experimental controls scored very high on absorption and did not report any idiopathic synesthesia. Notwithstanding, we did not test for spontaneous synesthesias and the tool may still be apt for that purpose.

The exploratory analyses

Some of our secondary results are more difficult to interpret and require some explanation. First, we deal with the simple null findings and then we move towards the findings of some interest.

Synesthetic Stroop

With regard to the synesthetic Stroop experiments. We found no relationship between absorption or the synesthesia subscale and the response time measures in the colour naming experiment, either for controls or synesthetes. A difference would be predicted both due to synesthesia and absorption. This may be explained by the fact that the colour naming Stroop task is one in which the participant has to focus and report on external stimuli and not internal imagery. Absorption therefore may not be of any assistance here. Whether absorption is tapped in this task is also questionable.

Absorption is not traditionally associated with attentional processes such as those that require volitional effort but with those that require passive attitude (Ott, 2003) such as meditation. On this basis, we might propose that this is why we do not see the effects manifest in our exploration. This experiment required considerable volitional effort and attention.

The level of the congruity effect in the associated colour naming experiment was positively correlated with the synesthesia subscale of the MODTAS but not with the whole scale. High scores on the synesthesia subscale predict higher congruity effects. This difference is likely attributable to increasing incongruent RTs. Since this subscale taps into a variety of synesthetic experiences (such as odour to colour, music to colour etc.) it is possible that the results indicate that those reporting poly-modal synesthesias are more susceptible to the distracting dimensions of the incongruent stimulus (rather than being able to take advantage of the irrelevant congruent dimension). Since this experiment asks participants to attend and give the response of their internally generated association a facilitatory effect which correlated with absorption would be expected, at least for synesthetes. Without the inclusion of a control condition however, this suggestion must be considered speculative and remains to be tested. We recommend that this issue be further investigated by conducting supplementary synesthetic Stroop experiments utilising the recommended changes to the method that we suggested in Chapter 4.

Tests of genuineness

Our most revealing investigation was that made as a result of looking at correlations between absorption and the GCAT scores.

A major finding was that GCAT scores are strongly but counter-intuitively correlated with absorption. The higher the absorption score the more variation in the grapheme-colour set and the less specificity is seen across the three iterations of grapheme to colour selections. The lower the absorption score the less variable the GCAT scores were. In Chapter 3, we found that the number of colour matches for orthographically similar graphemes in the set was negatively correlated with the variability score. The more colour matches based on orthographic similarity, the less variable the GCAT score. Even though absorption does not correlate with items relating to intellectual curiosity or need for orderly thought (Glisky, Tataryn, Tobias, Kihlstrom, & McConkey, 1991) that does not mean that these aspects do not affect how synesthetic translations are made. We pointed out previously that differences in the cognitive style of high and low absorbers has been proposed by Tellegen, (1981). Separately from the fact that synesthetes tend to be high absorbers, it is possible that these cognitive styles may influence the manner in which synesthetic associations are made, such that low absorbing synesthetes may adopt an instrumental style to the matching of colour to graphemes. This might be reflected as a sensible matching process between graphemes which share their orthography.

The above statements suggest that low scores on the absorption trait would correlate with inflexibility, and specifically a restricted grapheme-colour set, or one with few original colours and many form to colour (or indeed phonetic-colour) translations from an originally small inducing set. The systematic colour matching to orthographically similar shapes is negatively correlated with absorption for the synesthete group. If colour associations to graphemes are in any way the result of volitional or explicit influences, low absorption synesthetes should show evidence of realistic, voluntary, and relatively effortful planning, decision making, and goal directed behaviour, such as the matching of colour between similarly shaped numbers and letters. Of course we regard these statements as speculative. It is not yet proven that there are any explicit influences in the development of associations between colours and graphemes. However, to take the point one step further, if this speculation is helpful, then taken together this might drive the theories of associative learning of synesthesia a little further forward. These suggestions could be tested by longitudinal monitoring of the developmental trajectory of childhood synesthesia.

Since the absorption scale focuses on imagistic and aesthetic qualities we could speculate one other reason for our results. It is possible that low absorbers in our study may have less vivid or less variable experiences (rather than less variable reporting ability). Since we did not take any measures of the vividness of synesthesia we cannot comment but the strong correlation between measures of absorption and imagery make this a likely proposition worth testing. Barnett & Newell (2008) found that synesthetes do report higher levels of vividness of imagery than controls. Testing this aspect of synesthetic experience with absorption capability in conjunction with specific perceptual measures might tease this question out further. Absorption as a trait or as a state may speak to both the experiential component of synesthesia and to the translation component. We would predict that absorption would be positively correlated with vividness of the synesthetic experience. Moreover, since synesthesia is possible from internally represented inducers (Spiller & Jansari, 2008) or concepts (Dixon, Smilek, Cudahy, & Merikle, 2000) we recommend that strong vivid synesthetes and specifically projectors, not just associators, should be included in a sample for comparison purposes.

Even though it is highly suggestive, it is not yet certain that spontaneously generated synesthesias and idiopathic synesthesias share the same underlying aetiology. There are two major differences between these synesthesias. First idiopathic synesthesias have strong, consistent and durable associations over time, by definition spontaneous synesthesias do not. This issue has been raised several times in synesthesia research and crisply by Hunt (2005) who asserted that an important issue for research in synesthesia was to determine what is was that makes idiopathic synesthesias "so eidetic and fixed". We are far from a thorough explanation of this, but the work on the differences between the cognitive styles of high and low absorbers outlined by Tellegen (1981) seems a sensible place to begin.

Two final questions are of interest. What is the likely causal relationship between absorption and synesthesia and what do our results imply for the two main theories of synesthesia? In general, synesthesia researchers face a fundamental problem. We do not know whether the neuroimaging results which show stronger pathways between colour and language areas (Hubbard et al., 2005; Rouw & Scholte, 2007) are the cause or the effect of synesthesia. In conducting an exploratory assessment of absorption and idiopathic synesthesia we have the same problem and can ask a similar question of the data. Why could we expect idiopathic synesthetes to have higher levels of absorption? Does absorption in the object of ones early developmental play (i.e. fridge magnets, number jigsaws, etc.) create a heightened sense of reality and thus cause the cognitive restructuring required for synesthesia to occur – does it drive the binding of colour to form, or does the development of a capacity or disposition toward absorption reflect the interesting and captivating nature of one's internal representations? Simply it is too early to say. More research examining the developmental trajectory of childhood synesthesias is required to unravel this intricate issue. This will be difficult if we do not address the difficulties posed by virtue of the fact that the research literature is starkly divided between those who study spontaneous synesthesias and those who study the idiopathic variety with little overlap between them (but see Novoa & Hunt (2009) for a good attempt) and the difficulties disambiguating the phenomenology of both.

Grossenbacher & Lovelace (2001) propose the only theory of synesthesia which aims to account for both spontaneous synesthesias and idiopathic synesthesias. The theory is distinct from cross-modal connectivity and re-entrant theories since they do not suggest that synesthetes have special neuro-anatomical connections or aberrant structural relationships in the cortex. Grossenbacher & Lovelace (2001) argue that synesthesia arises from 'pathway convergence' between feed-forward and feed-back connections which is disinhibited in synesthetes. In the case of controls these connections may be sufficiently inhibited to avoid the induction of synesthesia. Thus, this would be consistent with the reports that synesthesia is evoked in meditation and drug induced states as no special connections are required. Since absorption and meditation are also well known to induce generalised cortical disinhibition our finding that synesthetes report more states of absorption and imaginative involvement supports the tenet that synesthesia and disinhibition are related in idiopathic synesthetes. It does not go so far as to support the suggestion of a causal link however and does not speak specifically either to disinhibition in feed-forward or feed-back mechanisms. This theory also does not speak to the relationship we have found between absorption and the structure of coloured grapheme pairs based on orthographic similarity. Further studies on these relationships are warranted. We suggest that studies which alter the level of absorption in ones internal representations in synesthesia (such as those further modifying attentional load) may reveal the state influences, not simply the trait influences, of absorption and their role in the induction of synesthesia.

Concluding remarks

To summarise, we found that idiopathic synesthetes have a greater propensity for absorbed involvement than controls. That absorption was negatively correlated with variability in synesthetic translation in the GCAT, and that synesthesia (as measured by the MODTAS subscale) was correlated with the Stroop congruency effect in the associated colour naming experiment.

With regard to the specific hypothesis of Glicksohn et al., (1999) we do not believe that the MODTAS is useful as a simple screening tool for synesthesia mainly because the MODTAS correlated negatively with the consistency of synesthetic translation, but also because many idiopathic synesthetes did not have high scores.

The findings of Ott et al., (2005) taken together with our confirmation that synesthetes are high absorbers appears to provide hope for success of the line of inquiry taken by Brang & Ramachandran (2008) in their investigation of pharmacological basis of synesthesia. However, the relationship between idiopathic synesthesia and the spontaneous synesthesias encompassed by absorption may be mediated by other factors and as such their investigation may assist in disambiguating these differences if both types of synesthesia are considered.

7. MULTISENSORY INTEGRATION IN SYNESTHESIA

7.1. Introduction

Idiopathic synesthesia is often considered an example of multisensory integration. (Goller et al., 2009; Maurer & Mondloch, 2006; McCormick & Mamassian, 2008; Spector & Maurer, 2009). In this chapter the hypothesis that idiopathic synesthetes are more susceptible to multisensory illusions is investigated by testing coloured hearing synesthetes and controls on the sound induced flash illusion (Shams et al., 2000).

The sound induced flash illusion is a simple cross sensory illusion utilising basic visual and auditory (non linguistic) stimuli and is produced by presenting beeps and flashes simultaneously. It is an effect where audition biases vision. One flash accompanied by two beeps and perceived as two flashes is termed a fission illusion. Two flashes accompanied by one beep and perceived as one flash is termed a fusion illusion (Andersen, Tiippana, & Sams, 2004, 2005; Mishra, Martinez, & Hillyard, 2008; Shams, Ma, & Beierholm, 2005; Watkins, Shams, Tanaka, Haynes, & Rees, 2006). These illusions can be tested together in the same experiment by manipulating the number of flashes and beeps presented on each trial within a block. In this thesis, the illusions are jointly referred to as the sound induced fission and fusion illusions (SIFFI).

There is only one study to date of synesthesia using a multisensory illusion. It is one where vision biases audition. Bargary, Barnett, Mitchell, & Newell (2009) used the McGurk effect in linguistic synesthetes to investigate the multisensory nature of synesthesia. The McGurk effect describes the interaction between heard words and the visual cues (lip movements) of those words when spoken. Using this effect, the researchers determined that the colours elicited by the heard words were those that matched words that were perceived to have been said, not what was actually spoken. They concluded that synesthesia is elicited by late perceptual processing and that coloured speech synesthesia occurs only after "a significant amount of information processing has occurred". This finding supports that of Dixon et al., (2006) who showed that the meaning (not the physical form) of graphemic stimuli is pivotal in determining its colour. This finding does not sit well with the hypothesis that synesthesia is a result of early cross modal processing and suggests that higher multimodal integration is required to elicit synesthesia.

Several researchers have linked synesthesia to the fission illusion implying that the illusion may detect differences between adult synesthetes and controls in cross-sensory processing (Goller et al., 2009; Hubbard, 2008; McCormick & Mamassian, 2008; Spector & Maurer, 2009). One researcher makes specific predictions on this matter. The failed differentiation model of synesthesia Maurer & Mondloch, (2005) argues that adult synesthesia is a remnant of the undifferentiated cortex of infants, possibly due to a failure of neural pruning or inhibition in development. This lack of differentiation would make it difficult for young children to disambiguate a multimodal event into its separate modalities (Spector & Maurer, 2009). The logical conclusion of this argument is that if synesthesia is also the result of failed differentiation, synesthetes would be more susceptible to the SIFFI than controls.

There is some support for the hypothesis that there are differences in the direct pathways between audition and vision, of synesthetes and controls. Beeli, Esslen, & Jancke (2008) for example, show differences in the ERP waveforms of synesthetes and controls to synesthetically inducing auditory stimuli as early as 122ms after stimulus onset in both auditory and colour areas. Barnett et al., (2008) have also shown that there are early ERP waveform differences in linguistic colour synesthetes at 65 to 85ms after the onset of non-inducing stimuli suggesting hyper-activation of early visual cortex (V1 and V2). Their data are compelling because they suggest that there are differences in the visual processing of synesthetes in areas such as V1 and V2 - differences which are not often seen in group fMRI synesthesia studies[20] due to large individual differences between synesthetes (Hubbard et al., 2005). Finally, Goller et al., (2009) presented brief tones to auditory-visual synesthetes (those who experience synesthesia for non-linguistic auditory stimuli) and controls and found that differences in auditory evoked potentials between the groups emerged as early as 100ms after the onset of the tone. However, they did not find similar effects to those reported in the SIFFI by Mishra, Martinez, Sejnowski, & Hillyard (2007). They also compared their results to those presented in studies of infants and concluded that the differences seen in the ERPs of auditory visual synesthetes are quite different both to those reported in this illusion with controls and to those seen in children. This presents the alternative possibility that differences between synesthetes and controls may not be seen in the experiment because the early cross sensory mechanisms which mediate this illusion may be quite different to those which mediate coloured hearing synesthesia.

[20] see Aleman, Rutten, Sitskoorn, Dautzenberg, & Ramsey (2001) for a single case

Concerns that the illusions are the result of criterion shift rather than any actual effect of the illusion have been expressed by researchers (McCormick & Mamassian, 2005). It is therefore necessary to ensure that any differences seen between the groups are not the result of response bias. SDT is used to measure the responses of participants in both baseline and illusion conditions. Measures of subjective signal strength and any response bias which may be present are taken.

7.2. Aim and Hypothesis - Experiment 8

The aim of Experiment 8 is to test the theory that synesthetes have failed differentiation and therefore have difficulty disambiguating multimodal stimuli. The hypothesis is that synesthetes will be more susceptible to the SIFFI than controls as measured by subjective signal strength (d').

7.3. Method

7.3.1. Participants

Twenty-two synesthetes (21 linguistic-colour, 1 sound-colour; 7 males) and thirty-one control participants (12 males) undertook this experiment.

All synesthete participants reported coloured hearing[21]. 32% of synesthetes reported coloured concurrents to pure auditory (non-linguistic) stimuli. Several participants also reported concurrents other than colour for heard sounds. One control participant's data was excluded due to computer error in the presentation of stimuli.

To ensure that there were no linguistic colour synesthetes in our control sample, we had all participants complete the GCAT described in Chapter 2. We also debriefed control participants about synesthesia and asked if they had any such experiences. None reported any synesthesia. There was a significant difference in the GCAT scores between the groups with the linguistic colour synesthetes (N = 20, M = 0.73, S.E. = 0.07) achieving better colour match consistency scores than controls (N = 30, M = 2.027, S.E. = 0.15). $t(50) = 7.02$, $p < 0.001$. Four control participants scored in the synesthesia range but denied having any forms of synesthesia. One was available for retesting, which confirmed a lack of long-standing associations over time. One

[21] We adopt the definition used by Beeli, et al. (2008). "persons who see colors when hearing words or sounds.

synesthete scored above the recommended diagnostic score of 1.12. The remaining synesthete who reported sound-colour but not grapheme-colour synesthesia was reinterviewed and showed consistent and durable associations over time for their inducing stimuli. Thus all synesthetes passed a TOG.

All participants were either volunteers, reimbursed $20 per hour of testing or received course credit for their time involved. All participants gave informed consent and the study was approved by the Human Research Ethics Committee of the University of Sydney.

7.3.2. Stimuli and Procedure

The stimulus configuration was the same as that used by Andersen et al., (2004) and similar to those in the original paper by Shams et al., (2000). However the duration of the stimulus and its synchrony differed slightly from these experiments.

Participants sat in a sound attenuated room with no additional lighting. Visual stimuli were presented on a Sony Trinitron G620 CRT monitor at a refresh rate of 100 Hz. The monitor was 70 cm in front of the participant. Participants maintained the same distance from the screen on each block through the use of a chin rest. Before each block, participants were reminded to keep their head placed on the chinrest and to maintain gaze on the fixation cross.

There were three single visual stimuli where one, two or three flashes were presented. A flash was a white dot. Luminance was 91 cd/m_2 on a black background which had a luminance of 0.23 cd/m_2. The duration of a flash was 10 ms. The diameter of the disk was 2.28 cm and it subtended approximately 2 degrees of visual angle. The centre of the disk was approximately 5 degrees eccentricity below the fixation cross. Auditory stimuli were beeps of sine-waves constructed in Goldwave v5.23 with a frequency of 3500 Hz and duration of 10 ms. The sound level of the beeps was 56 dB(A) at source, and was presented through Digitor brand headphones. The audiovisual stimuli were the nine combinations of the three auditory and the three visual stimuli. Stimuli were always presented synchronously and this was verified using an oscilloscope.

The twelve stimulus combinations that are presented in this experiment are illustrated in Figure 7-1.

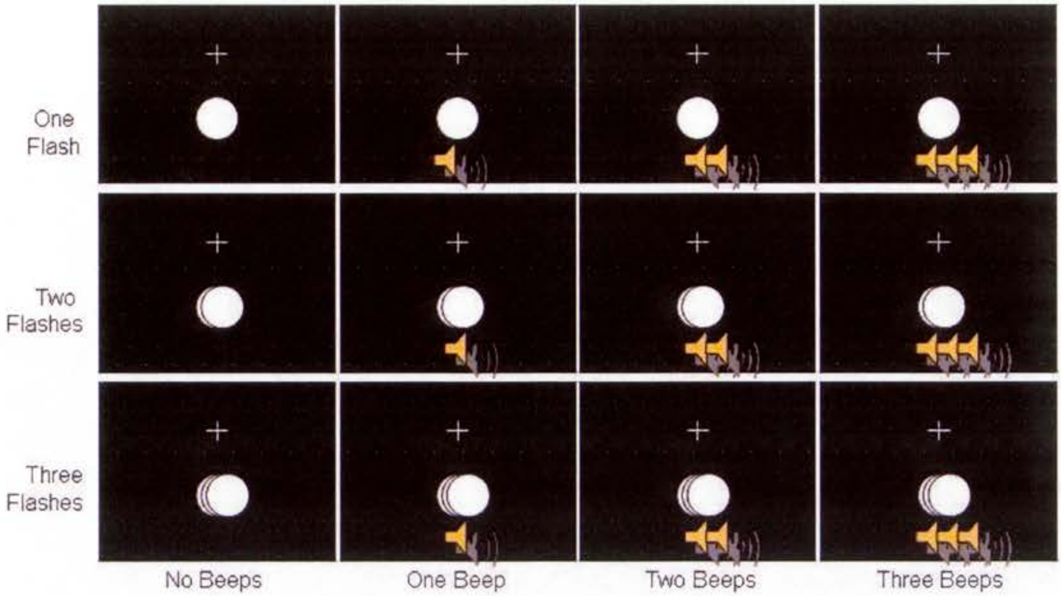

Figure 7-1. Illustration of SIFFI stimuli

The first beep and flash were delivered simultaneously with no asynchrony. Successive beeps were delivered synchronously with the onset of any flashes presented 60ms after the end of the previous flash. Illustrated in Figure 7-2 is the trial procedure for a 3 beep and 3 flash condition. It can easily be seen how the other conditions are arrived at simply by removing one or more of either the beeps or flashes presented.

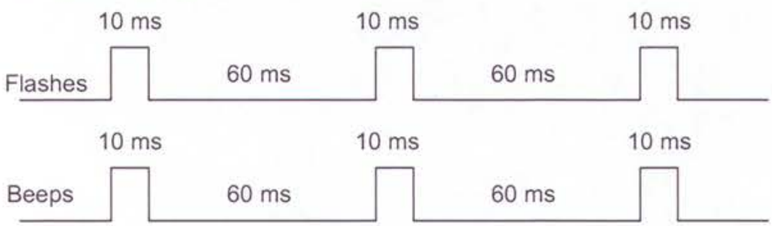

Figure 7-2. Illustration of the order of presentation of SIFFI stimuli

Participants indicated the presence of one, two or three flashes by a keyboard key press of the numbers one, two or three. Each block was composed of 10 presentations of each stimulus presented in random order, making a total of 120 trials. Participants completed between three and five blocks. In each block participants were instructed to count the flashes and ignore the beeps.

7.4. Results

Raw data

Figure 7-3 shows the raw data in percentage of responses for all conditions. Both groups experienced the different conditions in the experiment similarly with no obvious differences between the groups in the raw data. Participants were highly accurate when flashes equalled beeps, obtaining over 70% accuracy in these conditions. On 1 flash 2 beep (fission) trials, synesthete participants reported an illusory perception of two or more flashes on 64% of trials and control participants on 56%. These are not significantly different ($t(50) = 0.59$, $p = 0.55$). On 2 flash 1 beep (fusion) condition synesthete participants reported the illusion on 54% of trials and control participants on 50%. There was no significant difference between the presence of both illusions in raw count terms. ($t(50) = 0.495$, $p = 0.62$). This replicates the finding of Watkins, Shams, Josephs, & Rees (2007) though our raw % terms are higher.

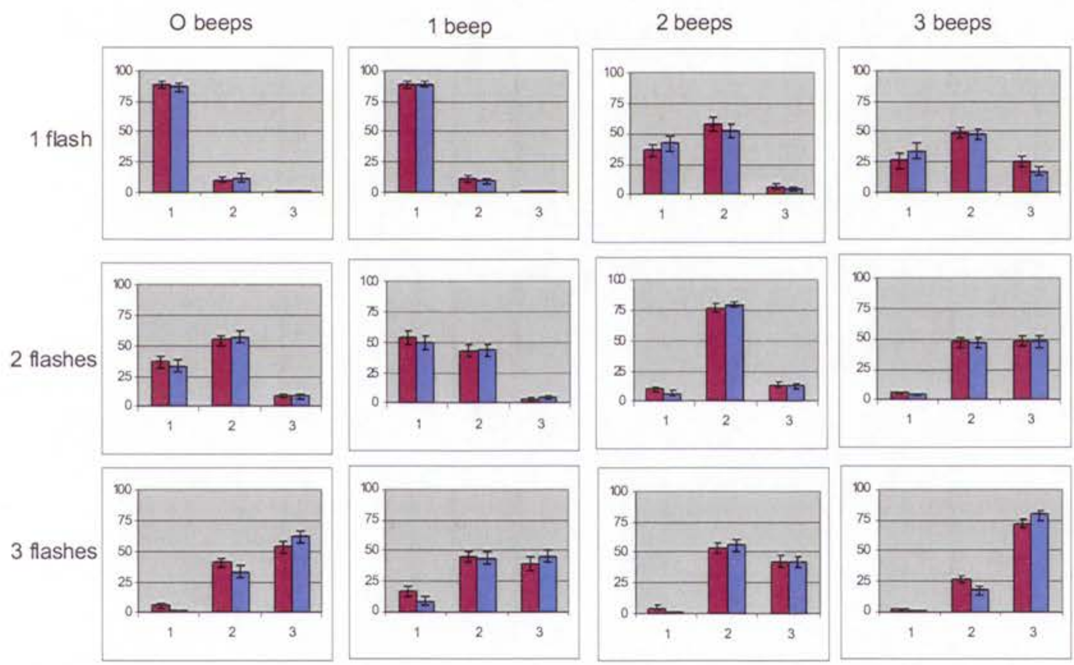

Figure 7-3. Percent responses in each SIFFI experiment condition. 1,2,3 indicate the number of flashes reported by participants. Controls shown in red, synesthetes shown in blue. Error bars are one S.E. of the mean

What is of interest in this experiment, however, is whether the groups perform differently in both illusion conditions relative to the baseline conditions.

Fission illusion

The SDT data are calculated as follows for the baseline: Hits = 2 or 3 flashes responses in the 2 flashes 0 beep condition, Misses = 1 flash responses in the 2 flashes 0 beep condition, False Alarms = 2 or 3 flashes responses in the 1 flash 0 beep condition, Correct Rejections = 1 flash responses in the 1 flash 0 beep condition.

The SDT data are calculated as follows for the fission illusion condition: Hits = 2 or 3 flash responses in the 2 flashes 2 beeps condition, Misses = 1 flash responses in the 2 flashes 2 beeps condition, False Alarms = 2 or 3 flashes responses in the 1 flash 2 beeps condition, Correct Rejections = 1 flash responses in the 1 flash 2 beeps condition. This is consistent with the approach of (Watkins et al., 2007). Figure 7-4 shows the results of this analysis.

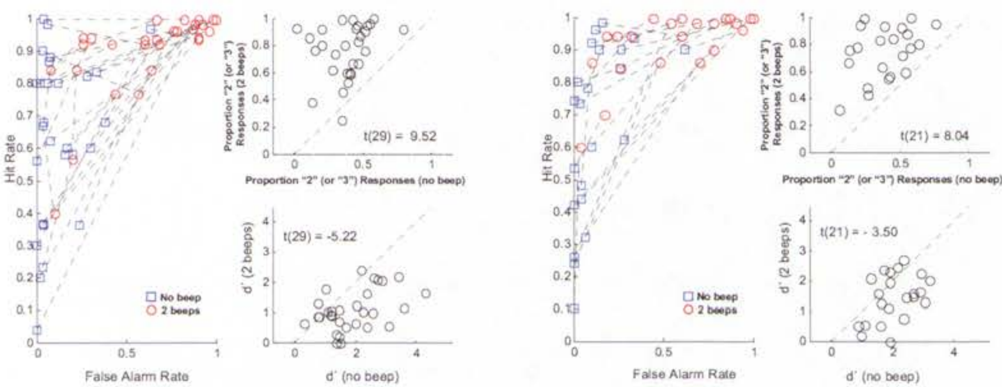

Figure 7-4. SDT graphs of *d'* and response bias in fission illusion condition vs. baseline. Controls shown on the left and synesthetes on the right.

For controls the decline in d' is from 1.92 in the baseline condition to 1.08 in the illusion condition, a significant difference $t(29) = -5.22$, $p < 0.001$. For synesthetes d' drops from 2.05 in the baseline condition to 1.47 in the illusion condition also a significant difference ($t(21) = -3.50$, $p < 0.001$). The groups do not differ in their level of sensitivity to the illusion (synesthetes: N = 22, mean *d'* difference = -0.59, S.E. = 0.17, controls: N = 30, mean *d'* difference = -0.84, S.E. = 0.16), $t(50) = 1.065$, $p = 0.292$.

We examined the values of the criterion, which we define as the average of the hit rate plus false alarm rate. Changes in criterion for both groups across both conditions are present, decreasing from 0.77 to 0.38 for controls and from 0.74 to 0.39 in the baseline condition for synesthetes. This is a similar decline to that reported by

McCormick & Mamassian (2008) but contradicts Watkins et al., (2006) who saw no such shift.

The response bias is larger in the illusion condition than in the baseline condition for both synesthetes ($t(29) = -9.52$, $p < 0.001$) and controls ($t(21) = -8.04$, $p < 0.001$). The groups do not differ in the extent of this criterion shift (synesthetes: N = 22, M = 0.36, S.E. = 0.04; controls, N = 30, M = 0.39 S.E. = 0.04), $t(50) = 0.668$, $p = 0.507$.

Fusion illusion

The SDT data is calculated as follows for the baseline: Hits = 1 flash responses in the 1 flash 0 beep condition, Misses = 2 or 3 flashes responses in the 1 flash 0 beeps condition, False Alarms = 1 flash responses in the 2 flashes 0 beep condition, Correct Rejections = 2 or 3 flash responses in the 2 flashes 0 beep condition.

The SDT data is calculated as follows for the fusion illusion condition: Hits = 1 flash responses in the 1 flash 1 beep condition, Misses = 2 or 3 flashes responses in the 1 flash 1 beep condition, False Alarms = 1 flash responses in the 2 flashes 1 beep condition, Correct Rejections = 2 or 3 flashes responses in the 2 flashes 1 beep condition.

Figure 7-5 illustrates the significant fusion illusion effect for both controls and synesthetes.

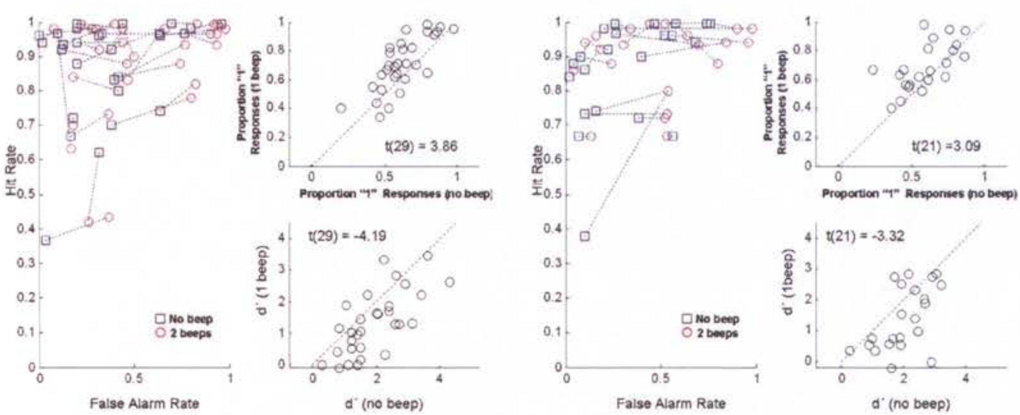

Figure 7-5. SDT graphs of *d'* and response bias in fusion illusion condition vs. baseline. Controls on the left and synesthetes on the right.

For controls the decline in *d'* is from 1.92 in the baseline condition to 1.34 in the illusion condition, a significant difference $t(29) = -4.19$, $p < 0.001$. For synesthetes *d'* drops from 2.01 in the baseline condition to 1.39 in the illusion condition, also a significant difference ($t(21) = -3.32$, $p < 0.001$).

The groups do not differ in the level of sensitivity to the illusion (synesthetes: N = 22, mean *d'* difference = -0.61, S.E. = 0.18; controls: N = 30, mean *d'* difference = -0.58, S.E. = 0.14), $t(50) = 0.154$, $p = 0.878$.

Small changes in criterion - which we calculated as the average of the hit rate plus the false alarm rate - for both groups across both conditions are seen, decreasing from 0.71 in the baseline condition to 0.62 in the illusion condition for controls and from 0.69 to 0.60 for synesthetes. The response bias present was also larger in the illusion condition than in the baseline condition for both synesthetes ($t(29) = -3.09$, $p < 0.001$) and controls ($t(21) = -3.85$, $p < 0.001$). The groups do not differ in the extent of their criterion shift (synesthetes: N = 22, M = 0.09, S.E. = 0.03; controls: N = 30, M = 0.08, S.E. = 0.02), $t(50) = 0.150$, $p = 0.881$.

7.5. General Discussion

There is no evidence that synesthetes perform any differently to controls in either the fission or fusion illusion conditions. They are neither more likely to respond in a biased way than controls, nor are they more or less susceptible to the illusions as measured by signal sensitivity change than controls. In short, at a behavioural level, the SIFFI cannot separate synesthetes from controls. Our results therefore do not support the prediction that synesthetes would be more susceptible to the illusion than controls and as such do not provide any evidence for the cross-modal transfer theories of synesthesia. Specifically, the theories of failed differentiation put by Harrison & Baron Cohen (1996) and Spector & Maurer (2009) are unsupported. We agree with the conclusion of Goller et al., (2009) that it is more likely that synesthesia – particularly its linguistic coloured hearing form - is due to different processes than those which result in this illusion.

The results are also problematic for the disinhibited-feedback theory of synesthesia. This theory is somewhat different to the failed differentiation hypothesis since it does not require any special aberrant or local cross connectivity, but it does propose a special location for multisensory integration in synesthesia. Grossenbacher & Lovelace

(2001) suggest the superior temporal sulcus (STS) is a strong candidate location for synesthetic integration. In this illusion the (STS) has been shown to play a role (Watkins et al., 2006). If coloured-hearing synesthesia occurs in this area – as a result of disinhibition – synesthetes should still be more susceptible to the illusion. We did not find this to be the case - at least for synesthetes for whom synesthesia is induced by heard linguistic stimuli. The proposition that the multisensory nexus of synesthesia is in the STS may not be entirely accurate or specific enough. Other locations, such as the anterior and caudal intraparietal sulcus (IPS) (Weiss et al., 2005) have been proposed for synesthetic integration and may be better candidates. Since this illusion does not appear to have any correlates in the IPS we might not likely see any differences in the illusion between synesthetes and controls as a result. Of course it is possible that there are differences in the STS between groups in the illusion conditions and they are too subtle to be picked up at a behavioural level. Barnett, Foxe et al., (2008) found differences in the visual evoked potentials (VEPs) between synesthetes and controls to (non inducing) visual stimuli which are not often found in fMRI studies. It is therefore possible that there are differences in processing – possibly in the STS or other multisensory regions - that are not captured at a behavioural level in this illusion.

One final aspect of this experiment may explain the lack of difference between synesthetes and controls. The taxonomic issues we raised in the introduction may be at work in our experiment. It is possible that coloured-hearing synesthetes are not coloured-hearing synesthetes at all and that the term is misleading with regard to the phenomenology of the experience. Perhaps there are significant differences in the locus or cause of synesthesia between those for whom pure auditory (non-linguistic) sounds evoke synesthesia and those for whom it is evoked by heard language. The SIFFI may only be able to find differences seen between this subtype of synesthetes and controls rather than the broader group we utilised for the experiment. In the experimental group, synesthesia is mainly elicited by conceptual linguistic units, and for the vast majority this is induced when heard or when written. This type of synesthesia may not need to recruit auditory processes and may be the result of higher level processing. Synesthesia could simply be the result of cross wiring in adjacent colour and language areas and a result of late conceptual processes. There is a great deal of evidence for this suggestion (Dixon et al., 2000; Dixon et al., 2006; Hong & Blake, 2007; Mattingley et al., 2001; Sagiv et al., 2006)

Even though the taxonomic issues may be a contributing factor, it is not the likely reason for our results because there did not appear to be detectable differences between the performance of the synesthetes with non linguistic coloured-hearing and those whose coloured-hearing is induced only by heard linguistic units. Visual inspection of the *d'* differences between the baseline and both illusion conditions for these synesthete participants are inconclusive with regard to differences between them and the rest of the synesthete group for whom non-linguistic stimuli evoked synesthesia less often or infrequently. There are participants in this group for whom the illusion was more pronounced and less pronounced than the group average. Any differences between these subtypes of synesthetes may not be large enough to be detectable in this experiment. The statistical power of our data in this regard is too small for full analysis. Notwithstanding this, even in the participants whose phenomenological reports were the most similar to the illusion conditions (non-linguistic auditory-visual synesthetes) there was no obvious influence of early cross-modal integration of the type elicited by the illusion.

Finally, in a related study, we tried making the stimuli more relevant to our linguistically based coloured hearing synesthete participants, by substituting a flashing white grapheme for the flashing white dot. A smaller group synesthetes (N = 9) was examined. This study is not reported in this thesis but both fission and fusion illusions were induced in the synesthetes. Using synesthetically inducing linguistic stimuli did not change synesthetes level of susceptibility to the illusion. This supports the suggestion that a different locus of multisensory integration is in operation in linguistic synesthesias to those utilised in the illusion and importantly it implies a lack of influence of one on the other. This mechanism by which this illusion is produced and the mechanism by which auditory-visual synesthesia is elicited may be vastly different and only further testing of purely non-linguistic auditory-visual synesthetes might resolve this problem. Given that many synesthetes are poly-modal, these participants may also be difficult to find.

In conclusion, we have found that synesthetes and controls perform similarly in the SIFFI - a result which would not be expected if synesthesia was the result of failed differentiation or was the result of disinhibition in the STS. We agree with Goller et al., (2009) that this illusion may not tap the same processes as those which induce coloured-hearing synesthesia. The SIFFI and possibly other auditory multisensory illusions may not therefore be helpful in demonstrating the basic nature of idiopathic synesthesia.

8. CONCLUSION AND FUTURE DIRECTIONS

This thesis has reported on several investigations into the nature of synesthesia and the methods used to explore it.

8.1. Diagnosing Synesthesia

In the introduction we argued that diagnosis of synesthesia is a difficult exercise not simply because it is problematic to take an inherently subjective experience and place it into an objective framework, but because the reports of synesthetes suggest that each individual's experience is highly idiosyncratic. We discussed Cytowic's (2002) five criteria for clinical diagnosis of idiopathic synesthesia and found that many of the characteristics of these criteria were shared with other members of the synesthesia family including acquired and spontaneous synesthesia. We then focussed our investigation on one of those five criteria; the consistency and durability in the reporting of specific synesthetic associations between inducer and concurrent pairs.

We started the investigation with inquiries of the TOG for synesthesia. Specifically, we examined the internal consistency paradigm. This was motivated by two issues. First, the TOG in general are widely used but have not themselves been rigorously examined for their diagnosticity and utility. Second, the internal consistency paradigm does not assess the durability of synesthetic associations and as such researchers cannot be certain whether the internal consistency method (and in particular the TOG of the Synesthesia Battery (Eagleman et al., 2007)), is an improvement in the testing of synesthesia or is at odds with the retest consistency paradigm. We assessed several different types of synesthesia using customised TOG for each type and evaluation of the internal consistency paradigm was undertaken by asking two questions. First, does the internal consistency paradigm give similar results and output to the retest consistency paradigm? Second, are the tests consistent with synesthetes' reports of their experience. We addressed this by exploring the qualitative reports of synesthetes undertaking the test and investigating sources of variability in the test results.

We found using the same statistical methods as those in previously published studies (t-tests) that TOG using the internal consistency paradigm differentiate between groups of synesthetes and controls in the same way that the retest consistency paradigm TOG do. They are at least as effective as the retest consistency paradigm for group level analysis. However, we found using SDT, that there is a great deal of variation between the different TOG in terms of how well they can diagnose an individual case. TOG for music and time units do quite poorly at individual diagnosis whereas TOG for sounds and graphemes do quite well.

Using SDT we derived different diagnostic scores which can be used by researchers to set the type of error they wish to control for. For grapheme-colour synesthesia, we have established a lower bound cut off score of 0.7 to control for Type I error and a more generous score of 1.5 to control for Type II error. A score of 1.12 was found to be of high signal intensity and recommended for general use. This differs only slightly from the recommended score of 1.0 originally proposed by Eagleman et al., (2007). In Chapter 2 we examined the speeded congruency test. Again, we found that it could adequately distinguish between the two groups. Using SDT we concluded that an accuracy score of 87.5% correct was best for individual diagnosis. We also recommended a variation in the way the test is administered to avoid an existing confound in the presentation of incongruent stimuli. We verified the claim by Eagleman et al., (2007) that the speeded congruency test was a useful addition to the TOG by showing that, in all but one case, control subjects misdiagnosed by the GCAT were excluded as synesthetes by the SCT. By administering the SCT after a delay that misdiagnosed case could also be excluded. We therefore recommended that, in future uses of the SCT, researchers administer it after a short delay, at least for those controls who score in the diagnostic range on the GCAT. The development of a SCT for the time unit TOG was also recommended.

We intensified our investigation of the TOG by expanding their breadth. The TOG for music and sounds were expanded to include testing for consistent reporting of shape concurrents. We failed to differentiate the groups in terms of the number of consistent shapes reported as concurrents. This was mainly because too few synesthete participants completed the test appropriately. We concluded that TOG may not be suitable for assessing this aspect of synesthesia because the nature of the shape concurrents experienced by synesthetes is highly varied and can be subtle. We recommend that further work to develop the taxonomy of shape concurrents in synesthesia is undertaken to guide future inquiries.

We compared the results of the GCAT test with the published results of Rich et al., (2005) and Simner et al., (2005) to find that there was large agreement between the output of the GCAT and the output of the retest consistency paradigm. There were only minor differences between the paradigms and of these, few could be attributed to the differences in methodology. We compared the output of the auditory musical notes TOG with the published results of Ward, Huckstep, et al., (2006) and also found similar results to theirs. In short, we concluded that the results that are derived from the internal consistency method do not differ substantially from the output of the retest consistency paradigm and are not at odds with it.

We completed our investigation of the TOG by considering what qualitative issues might have affected the accuracy of the TOG in particular cases. We found that synesthetes' experiences are considerably broader than that examined by the TOG. This was not an unexpected finding. However, we did find that some of these differences could contribute to high levels of variability and therefore contribute to Type II error decisions of researchers. When we examined the test results with the qualitative reports of synesthetes we found that individual variability in the test results could be attributed to several factors unrelated to the method of inquiry but specifically related to the phenomenology of the synesthesia reported by the participants. For example, the grapheme-colour TOG assumes there is only one colour experienced by a synesthete in relation to a specific grapheme. This was not always the case. Several synesthetes who reported colour associations for individual notes or for timbre performed poorly in the music-colour TOG because they could not identify the note played. In these cases their synesthetic experience was related to the playing of an instrument or the reading of musical notation and not passive listening. Further, in the test of time units, control subjects performed so well that the TOG generated a large number of false alarms. We concluded that this was possibly because control participants used chunking strategies, based on breaking down twelve months into seasons for example, in order to make the colour associations they reported in the test more memorable. For scores which lie at the diagnostic boundary, researchers would be advised to investigate the data for these sources of variability before making a final diagnosis.

In summary, we concluded that the internal consistency paradigm was at least as effective as the retest consistency paradigm as it provided similar quantitative and qualitative output and results. Further, the TOG of the Synesthesia Battery are easy to administer, provide superior output which is also easy to visually examine, and can be conducted in one session.

A second study described in this thesis also speaks to the issue of diagnosticity. It has been claimed that the synesthetic Stroop effect is a diagnostic marker of synesthesia. We found that the Stroop effect could be elicited in non-synesthetes in both synesthetic Stoop paradigms. This suggests that the effect is not unique to synesthetes and may therefore be unhelpful as a diagnostic tool in its current form. The Stroop effects elicited in the experiment however, did differ between the groups over the time course of the experiment and this may be helpful as a diagnostic marker. Further work is needed.

A third study described in this thesis also speaks to the issue of diagnosticity. In Chapter 6, we examined the claim of Glicksohn et al., (1999) that individuals with a high capacity for absorption would likely be synesthetes or eidetics. We reviewed previous investigations of synesthesia and absorption (which had defined synesthesia as cross-modal translation ability and synesthetes as individuals who demonstrated prototypical performance in this task). We took these previous investigations one step further by testing a group of idiopathic grapheme-colour synesthetes (many of whom were also poly-modal) against two groups of controls to discern whether synesthetes reported higher levels of absorption. The first group were participants in a range of other testing in our lab between 2007 and 2009, and the other group were a large cohort of first year psychology students. We administered the latest version of the Tellegen Absorption Scale (TAS), the MODTAS (Jamieson, 2005). We found that synesthetes and controls could be differentiated on the basis of their mean absorption scores suggesting that synesthetes on the whole report higher levels of absorbed or attentive engagement in everyday activities. This was also found to be true for all the subscale measures of the MODTAS except for ESP. Our investigations of the MODTAS scores between the groups however, revealed that the distribution of scores overlapped heavily. Further, we found a compelling and somewhat curious relationship between the colour match consistency score of the GCAT and the MODTAS. The highest scores were found in the synesthete group which was consistent with the claim of Glicksohn et al., (1999) but high absorption scores in the synesthete group were correlated with a low level of consistency (high scores) on the GCAT. Thus, high absorbing synesthetes are more likely to do poorly on the GCAT instead of better. With regard to the specific hypothesis of Glicksohn et al., (1999) we concluded that the MODTAS was not useful as a screening tool for synesthesia as many idiopathic synesthetes did not have high scores and also because it was counter intuitively correlated with the GCAT scores.

8.2. Taxonomy And Phenomenology of Synesthesia

In the introduction of this thesis, we considered the taxonomy of synesthesia and described the difficulties which currently exist in the field. Such difficulties are exemplified by the fact that multiple descriptions are used for similar synesthesias and it is often unclear precisely what a group of synesthetes has in common in a research study. In particular we described how the terms 'coloured-hearing', 'auditory-visual' and 'coloured-grapheme' synesthesia often overlap. The full force of this taxonomic problem was felt in the SIFFI experiment in Chapter 7, where the interpretation of the results of this and other studies were challenged.

Two main factors make a taxonomy of synesthesia difficult to develop. First, approximately 50% of synesthetes experience many different types of synesthesias and they also experience them in highly idiosyncratic ways. The same individual may report coloured graphemes, coloured heard words, coloured musical notes and coloured environmental sounds. They may also report multiple concurrents to the same inducing stimuli. In this case a synesthete would fit many descriptive classifications, of which some are not mutually exclusive. Second, there are varieties of synesthesia for which we have so little understanding of their phenomenology, that making planned inquiries is difficult.

In Chapter 5, we continued our investigation of the phenomenology of synesthesia by asking how more complex cases of synesthesia challenge and extend explanations and theoretical accounts of the condition. We described two cases of poly-modal and multi-concurrent synesthesia where not only colour but shapes and motion are elicited by inducing stimuli. In one of these cases other features such as personality and gender are also induced. It is clear from these cases that the existing explanations of synesthesia might be limited and inadequate. We discussed the need to further refine the terms projector and associator as well as the need to develop a library of poly-modal or multi-concurrent cases. The case studies also illustrated the pressing need for a taxonomy to describe the shape/form concurrents in synesthesia. A conclusion we drew after examining these two cases was that the preoccupation with colour as a concurrent might be obscuring a more fundamental aspect of the synesthetic experience; that form is a fundamental unit of the concurrent experience and that colour is bound to it. Concurrent colour is not sitting idly by as a patch of colour or a vague idea of colour. In fact, according to Ward et al., (2007), most associators report that the colour is bound to the grapheme. We argue that when shapes or forms are reported as explicit concurrent experiences they have several attributes. These attributes include, but are not limited to, colour, texture, motion and location in 3D space. Texture, motion, position and colour are aspects of the overall form/shape of the concurrent experience. In short, what might have been overlooked is that there may be other ways to frame questions for synesthetic inquiry. Rather than ask what is important about colour we could ask; what is important about the form to which the concurrent colour is bound? This would extend and refine the current classification of projectors and associators by requiring clarification of form boundaries, not just location. This line of inquiry could also be extended to motion or texture and other synesthesia types.

A second conclusion we drew was that poly-modal and multi-concurrent cases challenge the local cross-wired hypothesis of synesthesia to a greater extent than the disinhibition hypothesis. The local cross-wired hypothesis as it is currently put, requires expansion to account for why graphemes induce several synesthetic concurrents, some of which might not be processed in areas that lie adjacent to the Fusiform Gyrus where graphemes and colour are processed. Distal cross-wired hypotheses might account for these cases more appropriately but are insufficiently stated for us to comment upon in relation to these cases. More importantly they do not specify how these associations are made and how they might form a coherent whole.

Understanding the phenomenology of multi-concurrent synesthesias is likely to be an important first step in progressing the explanations of synesthesia. If sufficient cases are found then they can be compared for systematic pairing of concurrents. Given that there are so few cases in the literature describing multi-concurrent synesthesias, our conclusions were broad and suggestive. We concluded that asking whether some combinations of multiple concurrents were more or less likely might be a helpful way to progress our understanding. However, in the case of EL, where gender and personality are separate but simultaneously elicited concurrents of graphemes with colour and shape, we might also ask how localised cross-wiring might explain these varied concurrent types. We might also ask why the emotional synesthesias do not have personalities or gender. Is their neuroanatomical basis different? Are the neuroanatomical centres of these synesthesias processed in regions distant from the places where the inducing stimulus is processed? Such cases might also inform us as to the localisation of processing in normal perception. How binding of features occurs and how single objects become concepts or categorical representations might well be informed by investigations of synesthesia.

8.3. The Role of Implicit and Explicit Learning

In Chapters 2 and 3 we examined the GCAT data for systematic patterns of colour matching to graphemes. Like Simner et al., (2005) we also found that there are systematic influences such as letter use frequency and colour name frequency in grapheme-colour pairings suggesting that exposure to frequent stimuli has a role to play in explaining idiopathic synesthesia's aetiology.

We have seen that other types of environmental influences are also at work. We have shown that these associations can be personally relevant, such that the colour of the initial letter of one's name tends to be gender specific, pink for girls and blue for boys. This suggests that pervasive and personally specific attentional factors are also involved in the development of colour associations of synesthetes.

What do our investigations imply for the hypothesis that synesthetic associations are learned implicitly? Implicit learning is defined as "non-episodic learning of complex information in an incidental manner, without awareness of what has been learned" (Seger, 1994). The fact that synesthetic adults cannot often identify the source of their colour associations does not make it implicit, just forgotten. The results presented in this thesis suggest a much more explicit form of systematic exposure may be involved, such as, constant and repeated contact in a conscious and deliberate manner. Asking synesthetic children what their colours for certain graphemes are as they are developing, would be a simple way to resolve this issue if the children can give a response. Evidence to support the associative learning accounts of synesthesia might be more forthcoming if the trajectory of the acquisition of the synesthetic colours to the graphemes from childhood was determined. This type of study has not been conducted to date. All that is currently available to researchers is the surviving grapheme-colour sets of adults. Future research considering longitudinal aspects of synesthetic colour acquisition could also determine what influences are primitive in deciding the colours that are allocated to graphemes. Questions such as which graphemes acquire their synesthetic correspondences first, whether they share visual sub-features or whether they are from the same categorical family might be addressed in this way.

What might be due to implicit processes is the transfer or migration of one grapheme-colour association to another. Given that there are 36 graphemes and 11 colour categories some graphemes must share their colour associations. We discovered that this occurs in a orderly fashion. Graphemes which share their colours are most likely to be orthographically similar and colour matching between graphemes occurs more often for different category pairs (number–letter) than same category pairs (letter-letter; number-number).

What is it that makes synesthetic colour associations enduring and perceptual? Is it the time spent (exposure) or is it possible that the type of attention and arousal (absorption) that this learning requires, is influential? One possibility that fits the observation that synesthetic associations are learned unconsciously or at least somewhat implicitly is that synesthetic learning involves absorbed states of consciousness and that as a whole synesthetes have a higher capacity for this kind of focused attention.

We concluded that synesthetes who make less specific and consistent matches in the GCAT might have a weaker or more diffuse synesthesia than those who have high levels of consistency. Since we also found that the GCAT score was moderated by the number of colour matches for orthographically similar shapes we inferred that these high consistency synesthetes might have synesthesias which arise earlier in the visual processing stream and are therefore more specific in their relationships with concurrents. They may also be elicited by the physical form of the inducer and not by its meaning, a conclusion that fits with the higher – lower synesthesia distinction of Ramachandran et al., (2002). More specific relationships might make for less ambiguity in the synesthetic response and may also therefore require less higher order processing resources. Future neuroimaging investigations of synesthesia might be directed at contrasting synesthetes with high and low levels of orthographically similar pairs to tease out the Ramachandran et al., (2002) theory. An alternative hypothesis was that high absorbers and low absorbers utilise different cognitive styles in the processing and learning of objects. Low absorbers utilise an inflexible instrumental style and high absorbers might utilise a flexible experiential one. This is the only obvious conclusion we could draw from the work of Tellegen (1981). One way to test this would be to compare the level of absorption or engagement of child synesthetes to stimuli which are synesthetic inducers with non-synesthetic children.

Whether concurrent colours are paired explicitly or implicitly, the weight of evidence in favour of associated learning of grapheme-colour pairs in development, is increasing. For theoretical accounts of associated learning in synesthesia to advance, what is needed is stronger alignment in future investigations with the literature on the developmental aspects of reading and category learning.

8.4. Is Synesthesia Automatic?

Like previous researchers we also wished to know if synesthesia was automatic and if so what was the contribution of synesthesia to the Stroop effects seen in previous experiments? In Chapter 4 we pursued this question using the standard Stroop format but we also addressed a considerable methodological limitation in previous research. This limitation made it possible that simple associations between colours and graphemes were responsible for the effects seen in synesthetes but not in controls in previous studies. In this study we built unique stimulus ensembles for both synesthetes and controls using their own idiosyncratically colour matched graphemes. This differed from previous studies where controls were tested using the synesthetes' stimuli. We found that both synesthetes and controls exhibited Stroop congruity and interference effects. The level of interference was also correlated to the colour match consistency scores in the GCAT, suggesting that response conflict in naming the associative link may be responsible for the effect.

Current opinion considers that Stroop interference is largely a response processing measure. This suggests that the synesthetic version of the test may simply be assessing the interference experienced in reporting an association between colours and graphemes rather than the early and automatic evocation of any perceptual element unique to synesthesia. Possibly the effect measures the strength or durability of the colour matched associations. This is consistent with the assertion by Ramachandran & Hubbard (2001a) that using the results of Stroop-like interference tasks to infer that synesthesia is either conceptual or sensory is unjustified, because it simply shows that the association between graphemes and colour are *automatic*. In our opinion synesthetic Stroop tests are likely to be exerting top-down influences in the task and it is the processing of the associative link that is automatic. There is sufficient evidence in the ERP and fMRI literature to support the view that Stroop effects can occur at multiple stages in the processing stream but the relationship between GCAT and interference suggests our effects are mainly tied to interference and therefore to response processing. Our results echo those of Cohen Kadosh, Henik, Catena, et al., (2009) who elicited synesthetic Stroop effects in non synesthetes after post hypnotic suggestion. In both studies the synesthetic Stroop effect is elicited in individuals who do not have any special cross-wiring in their neuroanatomy and who do not report any perceptual consequences of the association.

Further support for the suggestion that the synesthetic Stroop effect is not unique to synesthetes is that there was no group difference in the associated colour naming experiment. By using the unique stimulus ensembles of each individual we found that this test could not distinguish between the synesthete and control groups. One fortuitous additional opportunity was available to us to examine our conclusions. A projector synesthete reported coloured associations for both geometric shapes and for graphemes of which geometric shapes elicited weaker synesthesia. The comparative analysis between the results for both experiments of the single case study mimicked the between groups results in both the colour naming experiment and the associated colour naming experiment. Stroop interference effects were weaker for geometric shapes than graphemes, a result consistent with her assertion. We understand that generalising from a single case is contentious but the results are suggestive and future inquiries could be directed at examining our conclusions specifically.

We concluded that Stroop effects are largely uninformative with regard to automaticity of synesthesia because they are seen in the results of control participants. In short, synesthetic Stroop effects might not be entirely synesthetic.

8.5. Is Synesthesia a Classical Multisensory Phenomenon?

In Chapter 2 we administered a TOG for musical notes and interrogated the data for relationships between inducers and concurrents. Like previous researchers, we found that synesthetes and controls match pitch and brightness and pitch and saturation in similar ways. This suggests that the methods or principles of translation between sensory modalities may not be what distinguishes synesthesia. Our investigation into the multisensory nature of synesthesia was deepened in Chapter 7 by using the SIFFI to determine whether synesthetes were more susceptible to the illusion than the control group. We conducted this investigation on the basis of claims in the literature that synesthesia is the result of distal (and surviving neonatal) connections between sensory modalities. We found that neither synesthetes nor controls were more susceptible to the illusion than one another. This suggests that either synesthesia is not elicited or tapped in this test or that there is no discernable difference in the long range connections that unite the modalities of audition and vision between the groups.

8.6. Research Methods Used in the Experiments in this Thesis and their Limitations

In this thesis we have utilised a combination of qualitative and quantitative methods. In an emerging field such as synesthesia, this is inevitable as phenomenology necessarily drives scientific inquiry. We would be remiss if we did not point out that our own investigations are limited by the same taxonomic struggles we have seen in other studies. It is precisely because we struggled with them in designing and implementing our experiments and investigations, that they have become apparent.

In the introduction, we pointed out that progress in the field rests with making advances on several fundamental fronts. First, by establishing a stronger taxonomy, second by utilising new methods to address old, and construct new, questions and finally by using these to drive advances in theory. We hope that by scrutinising the internal consistency method for the TOG, establishing better diagnostic scores for them and drawing out features of the two case studies we have helped the research community and the field in general to understand a little better what synesthesia is, how it might manifest, and how it can be diagnosed. We have also used SDT to assess the TOG and provided a methodological improvement to the synesthetic Stroop test, one which if adopted by researchers in the future might give a better understanding of the condition and how synesthetes might differ from controls.

Finally, we have attempted to align our findings on orthographic shape similarity to the letter recognition literature. We know the attempt is preliminary but hope that framing the problem in this way may aid future researchers.

8.7. Outstanding Issues and Future Directions

In the introduction we outlined three core challenges that will drive the synesthesia research field forward. Although we have made some progress in addressing these core challenges, three key questions for future research are still with us. These are:

- What level and type of processing of the inducer is required before synesthesia can be elicited and where is this processing likely to occur?
- How does learning of stimulus pairs, such as graphemes and colours, survive development?
- How can poly-modal or multi-concurrent synesthesia be better explained?

Despite a growing literature base, investigating the perceptual reality and the causal basis of synesthesia is still complex. There is a great deal of literature both for and against the premises that synesthesia is largely conceptual in nature (Blake et al., 2005), and that the whole inducer and its meaning need to be processed. Further, there are challenges in the interpretation of these studies. For example, the challenge of determining the extent to which the task itself influences the outcome. Our finding that the synesthetic Stroop effect can be found in non-synesthetes simply by administering stimulus ensembles meaningful and unique to each individual, suggests that we need to reconsider the interpretation of preceding research, much of which rests on finding that the effect is not found in non-synesthetes. Most importantly, this implies that it might be more difficult to determine the level of processing required for synesthesia to occur as differences between synesthetes and controls in behavioural tests might be more subtle than previously thought.

There are still many behavioural paradigms as well as improving neuroimaging techniques that can be exploited to tease these questions out. For example, one approach to the first question would be to try the Bubbles Technique used by Fiset et al., (2009) mentioned in Chapter 3, to test idiopathic synesthetes directly. Systematic manipulation of the level or extent of grapheme features shown to subjects might break down the visual processing of grapheme recognition and provide evidence of whether combinations of features are required or whether indeed the whole grapheme requires identification to elicit a synesthetic response. Neuroimaging methods such as fMRI have already proven to be useful in differentiating groups of synesthetes from controls in many respects. DTI has shown that there is more coherent white matter in a range of areas that might be associated with synesthesia such as the left parietal and right temporal cortex. This method also distinguished projector synesthetes from non projectors (Rouw & Scholte, 2007). Using VBM techniques synesthetes have also been found to have increased grey matter volume in parietal areas (Weiss & Fink, 2009). The brains of grapheme-colour synesthetes have also been found to have increased cortical thickness, volume and surface area, bilaterally, in regions such as the Fusiform Gyrus (Jancke, Beeli, Eulig, & Hanggi, 2009). Multi Voxel Pattern Analysis (MVPA), a relatively new technique in neuroimaging, has the potential to directly predict the specific brain regions involved in grapheme-colour synesthesia. It is possible that a pattern classification algorithm could learn from brain activity whether synesthetes were perceiving synesthetically induced colours when viewing an array of black graphemes that evoke different synesthetic colours. This method might also be able to differentiate projector synesthetes from non projector synesthetes. Such methods are powerful new tools and will assist in identifying where processing of synesthesia occurs. Careful experimental design might also be able to address concurrently the question of what needs to be processed.

These types of investigations in adult populations are not able to answer our second question however, as studies of this type cannot speak to whether neuroanatomical differences are the cause or the result of synesthesia. The best way forward to answer this question is the long and hard road of longitudinal and developmental research. Above, we asked how does learning of stimulus pairs such as graphemes and colours survive development? What does make them so eidetic? We have found that synesthetes have a greater propensity to report absorbed states of attention in daily activities. Though highly speculative at this point, it is possible that such an attentional bias, if it exists in the synesthetic individual in childhood, may contribute to the condition by increasing the child's interest in, and attention to, any associations made between inducers and concurrents. Developmental and experimental studies of children directed at assessing their involvement and interest in play or imaginative involvement generally might speak to this issue.

Longitudinal investigations of child synesthetes both in terms of neuroanatomical investigations as well as observational studies are required to unravel this question further. Given the low incidence of synesthesia in the general population, these studies might be best conducted by recruiting the children of known synesthetes. Comparing children of synesthetes - who do and don't acquire synesthesia - with one another over a period of time in development, might also help answer why some children of synesthetes develop the condition and others do not. Broader investigations of child synesthetes might also help answer the question of why synesthesia develops in those without any family history. Such comparisons examining genetic markers, as well as, neuroanatomy through VBM and DTI could also reveal whether or not structural architecture is biased early in synesthesia or not, answering the question of whether the differences we seen in neuroanatomy in adults are the cause or consequence of synesthesia. Longitudinal and observational studies of the order in which graphemes acquire their colours will also help drive developmental theories of synesthesia forward. Such studies also have the potential to inform general theories of reading and object recognition as well as colour and form binding in perceptual development.

Collective approaches to research inquiry (across the whole field of researchers) may be a good way forward as this would give the strongest results. It would give legitimacy to the inquiry and could sustain the investigation independently of researchers coming and going into the field over time. To achieve significant success, the field of synesthesia researchers could come together to discuss an internationally collaborative project, decide on its parameters and execute it. We now know that we can have a high degree of confidence in the tests contained in the Synesthesia Battery and importantly, it is already available to all researchers in the field. It shows great promise for collaboration. The challenge ahead is to build from this offering, to develop new tools and methods, to develop collective approaches to data collection, define how this data is accessed, by whom and under what terms and, how the results of any collective analysis are interpreted.

Our final question asked how can poly-modal synesthesias and multi-concurrent synesthesia be better explained? What do the poly-modal synesthesias have in common and is there a defining causal mechanism common to them all? These questions brings us full circle back to the beginning of our inquiries; the importance of a strong taxonomy and phenomenology. We can see for the two case studies in Chapter 5 that the current explanations of synesthesia are challenged both in terms of specificity and in breadth. To explain these types of synesthesia we could first apply cross case analysis techniques to both phenomenological and experimental investigations. Synesthesia researchers may also need to abandon modular explanations in favour of integrated or distributed explanations of synesthesia. Currently, modular hypotheses are useful for constructing experiments and neuroanatomical investigations. It may be more likely that a unified theory that accounts for more than one form of synesthesia and the presence of many synesthesia types in an individual will be one which considers both bottom up and top down influences and networks of brain activity in the condition. The involvement and role of what are considered to be poly-modal processing areas must also be addressed. For example, in many of the neuroanatomical and functional neuroimaging studies we cited earlier, parietal and temporal areas are implicated, suggesting that localised cross-wiring may be necessary but not sufficient for synesthesia to occur.

8.8. Conclusion

The mind does not give up its secrets easily as well our investigation into synesthesia a testifies. However, with advances in our understanding of synesthesia, the secrets of the mind might become a little closer to being unlocked than they ever have been before. Synesthesia has a lot to offer neuro-scientific inquiry and we hope that our small offerings will assist future researchers to turn the key.

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APPENDIX A: THE MODTAS QUESTIONNAIRE

INSTRUCTIONS

Please fill in the following questionnaire by circling the number which corresponds to how frequently each of the following statements is true of your experience. Where 0 means "never", 1 means "at least once", 2 means "occasionally", 3 means "often" and 4 means "very often". It is imperative that you answer these questions as honestly as possible. Please do not return this questionnaire if you do not feel you have been able to cooperate with this request.

1. I feel and experience things as I did when I was a child. 0 1 2 3 4
2. I am greatly moved by eloquent or poetic language. 0 1 2 3 4
3. While watching a movie, a T.V. show, or a play I become so involved that I forget about myself and my surroundings and experience the story as if it were real and as if I were taking part in it. 0 1 2 3 4
4. If I stare at a picture and then look away from it, I can "see" an image of the picture, almost as if I were still looking at it. 0 1 2 3 4
5. I feel as if my mind could envelop the whole world. 0 1 2 3 4
6. I like to watch cloud shapes change in the sky. 0 1 2 3 4
7. I imagine (or daydream) some things so vividly that they hold my attention as a good movie or story does. 0 1 2 3 4
8. I think I really know what some people mean when they talk about mystical experiences. 0 1 2 3 4
9. I "step outside" my usual self and experience an entirely different state of being. 0 1 2 3 4
10. Textures - such as wool, sand, wood - remind me of colours. 0 1 2 3 4
11. I experience things as if they were doubly real. 0 1 2 3 4
12. When I listen to music, I get so caught up in it that I don't notice anything else. 0 1 2 3 4
13. If I wish, I can imagine that my body is so heavy that I could not move it if I wanted to. 0 1 2 3 4
14. I somehow sense the presence of another person before I actually see or hear her/him. 0 1 2 3 4
15. The crackle and flames of a wood fire stimulate my imagination. 0 1 2 3 4
16. I become completely immersed in nature or in art and feel as if my whole state of consciousness has somehow been temporarily altered. 0 1 2 3 4

17. Different colours have distinctive and special meanings for me. 0 1 2 3 4

18. I wander off into my own thoughts while doing a routine task and actually forget that I am doing the task, and then find a few minutes later that I have completed it. 0 1 2 3 4

19. I recollect certain past experiences in my life with such clarity and vividness that it is like living them again or almost so. 0 1 2 3 4

20. Some things that might seem meaningless to others make sense to me. 0 1 2 3 4

21. While acting in a play I think I could really feel the emotions of the character and "become" her/him for the time being, forgetting myself and the audience. 0 1 2 3 4

22. My thoughts don't occur as words but as visual images. 0 1 2 3 4

23. I take delight in small things (like the five-pointed star shape that appears when you cut an apple across the core or the colours in soap bubbles. 0 1 2 3 4

24. When listening to organ music or other powerful music, I feel as if I am being lifted into the air. 0 1 2 3 4

25. I can change noise into music by the way I listen to it. 0 1 2 3 4

26. Some of my most vivid memories are called up by scents and smells. 0 1 2 3 4

27. Certain pieces of music remind me of pictures or moving patterns of colour. 0 1 2 3 4

28. I know what someone is going to say before he or she says it. 0 1 2 3 4

29. I have "physical memories": for example, after I've been swimming I may still feel as if I'm in the water. 0 1 2 3 4

30. The sound of a voice can be so fascinating to me that I can just go on listening to it. 0 1 2 3 4

31. I somehow feel the presence of someone who is not physically there. 0 1 2 3 4

32. Thoughts and images come to me without the slightest effort on my part. 0 1 2 3 4

33. I find that different odours have different colours. 0 1 2 3 4

34. I am deeply moved by a sunset. 0 1 2 3 4

APPENDIX B: THE SYNESTHESIA EXPERIENCES CHECKLIST

Please answer yes or no to the following questions.
Please indicate yes even if it is only true some of the time.

1) Letters, or words tend to have specific colours for me (e.g. the letter A may be red): Yes /No

2) Time units (such as days and months) have special colours for me: Yes/No

3) Numbers have specific colours for me (e.g. the number 2 may be blue): Yes /No

4) Numbers, months or dates are arranged in special spatial locations for me: Yes/No

5) Sounds (including spoken words) or music evoke different colours for me: Yes /No

6) Sounds (including spoken words) or music evoke different shapes for me: Yes /No

7) Sounds – (including spoken words) elicit specific tastes for me: Yes/No

8) Smells have specific colours or shapes for me: Yes/No

9) Tastes have shapes or colours for me: Yes/ No

APPENDIX C: LIST OF SHAPES USED IN THE MCSAT AND SCSAT AND THE GEOMETRIC SHAPES TOG

These were used as names in the TOG. Pictures of these were used in the geometric shape-colour TOG and the subsequent geometric shape synesthetic Stroop test.

Booba, circle, cone, cube, cylinder, heart, hexagon, kiki, moon, octagon, oval, parallelogram, pentagon, pyramid, rectangle, semicircle, square, star, trapezium triangle, whorl.

APPENDIX D: LOWERCASE LETTER CONFUSABILITY MATRIX

a b; b d; b e; b h; b q; c o; d h; d i; d p; d q; e o; f i; h n; h u; i j; i l; j t; j z; k v; m n; n u; p q; r y; t y; v y.

APPENDIX E: UPPERCASE LETTER CONFUSABILITY MATRIX

A H; A K; A M; A T; A X; A Y; B E; E F; E H; E T; F H; F T; H K; H T; K M; K T; K Y; M W; M Y; P R; A E; A F; A V; A W; B H; B K; B M; B P; B R; B T; E K; E L; E M; F K; F L; F P; F R; H I; H M; H P; H R; H Y; I K; I M; I T; I Y; K N; K P; K R; K V; K W; K X; L T; M N; M R; M T; M V; M X; N R; P T; Q R; R T; R Y; T Y; V W;V X; V Y; W X; W Y; X Y.

APPENDIX F: MATRIX OF ORTHOGRAPHICALLY SIMILAR GRAPHEME PAIRS

0 0; 0 C; 0 D; 0 Q; 1 I; 1 L; 1 T; 2 5; 2 N; 2 S; 2 Z; 3 8; 3 E; 3 M; 3 W; 4 A; 4 H; 5 S; 6 9; 6 b; 6 g; 6 p; 6 q; 7 J; 7 L; 7 V; 8 B; 8 S; 9 b; 9 g; 9 P; 9 q; A V; b d; b p; b q; C O; C U; C D; d p; d q; D O; D U; E F; E M; E W; f t; h y; h n; h u; I l; I T; J L; J T; L T; m n ; M W; n u; n z; n s; O Q; p q; P R; S Z; t x; U V; U W; V W; V X; V Y.

APPENDIX G: TABLES OF INDUCER - CONCURRENT PAIRS FOR EL

Inducer	Colour	Shape	Texture/ Temperature	Strength	Any other comment (personality)	Gender
0	clear – tinge of blue	water droplets, misty	translucent	W		neuter
1	strong white		flat like paper	S	straight-forward person	M
2	red		plastic, flat	S	practical person	M
3	yellow	curved	soft, furry, little bumps like a dust cloth, warm	S	cheerful, bit silly/ clumsy, warm-hearted	F
4	blue	tall glass tower	sharp, glassy, translucent, cold	S	rational, logical, stern, tall glass tower than continues upwards infinitely	M
5	orange-pink	curved	plastic, warm	S	warm-hearted, relaxed, easy going, associated with H and R	F
6	purple	blob, curved	soft	S	associated with p, relaxed but sometimes angry	F
7	light green		sharp and spiky	S	bit shifty/ dodgy, associated with f	M
8	dark green		lumpy	S	stern and rational but less so than 4 – has a soft side, natural, associated with g	M
9	dark purple – black	curved	flat	S	angry person	F

Inducer	**Colour** (where there is a dash, the first colour is dominant)	Shape	Texture	Strength	Any other comment	Gender
A	dark blue		flat like paper	S		M
B	light brown		sandpaper bumps	M		M
C	pale green – yellow		flat	M		F
D	dark grey		few soft bumps	M		M

Inducer	**Colour** (where there is a dash, the first colour is dominant)	Shape	Texture	Strength	Any other comment	Gender
E	pink	curved	soft	S	associated with my name, childhood favourite colour, colour of pleasure	F
F	light green		flat	M	associated with frog and fear	M
G	dark green		flat	M		M
H	orange	curved	plastic: smooth, hard, shiny	S	same texture as capital R, number 2 and 5	M
I	clear – pale yellow	fluid blob	watery, translucent	W		F
J	pale yellow – orange tinge	fluid blob like jelly	watery, translucent	W		F
K	rich green		flat	S		F
L	pale yellow	bit fluid like egg white	watery	M		F
M	rich red		plastic	S		M
N	orange – red		plastic	S		M
O	brown		few bumps	M	associated with owl	M
P	purple – red		plastic	S	associated with number 6	F
Q	khaki green		thick liquid	M	the colour of guilt	M
R	green		flat	M	smells like freshly cut grass	M
S	bright yellow		plastic	S	associated with sun	F
T	bright blue		plastic	S		M
U	grey – blue		like cotton wool: soft	W		F
V	green – grey		flat	W		F
W	grey – pale yellow		bit woolly	W		F
X	gold – grey		metallic like a golden cymbal	W	associated with xylophone	M
Y	pale yellow – grey	fluid blob	watery	M		F
Z	gold		metallic	S		M

Inducer	Colour	Shape	Texture/ Temperature	Strength	Any other comment
Monday	red		plastic, flat	S	associated with 2
Tuesday	blue		glass	S	associated with 4
Wednesday	yellow	round, curved	soft, furry	S	associated with 3
Thursday	purple – blue – grey	curved	woolly	M	sound 'th' makes it woolly
Friday	dark green		lumpy	S	associated with 8 and Japanese character kinyobi (gold day)
Saturday	dark grey - yellow		warm	M	associated with Japanese character doyobi (earth/ soil day) so it's grey for earth and yellow for s
Sunday	bright yellow	square like Japanese character	hot	S	associated with the sun and Japanese character nichiyobi (sun day)

Inducer	Colour	Shape	Texture/ Temperature	Strength	Any other comment
January	pale yellow – orange tinge	blob like jelly	bit translucent	M	
February	green - grey			M	
March	rich red		flat, plastic	S	like Monday and number 2
April	blue	sharp points	cold	S	sharp, bright, crisp
May	red	curved	softer than March	S	
June	pale yellow		bit translucent	W	I always get June and July confused because they are the same colour
July	pale yellow		bit translucent	W	
August	dark blue	round	thicker/ heavier than April	M	u and g make it darker/ guttural sound of g
September	yellow	curved	light and fluffy	S	cheerful like number 3
October	pink	curved	soft, warm	S	associated with my birthday and letter e
November	orange – brown		plastic	M	
December	dark grey		thick wool, soft	S	

Inducer - Timbre	Colour	Shape	Texture	Strength	Any other comment
		as a general rule sounds travel from left to right			high sounds are red, low sounds get darker – usually dark blue/ grey
Piano	blue, some pink	rectangles	smooth	M	
Violin	turquoise green/ blue, high notes red	thin waves	sharp	M	
Cello	dark blue	thick waves	smooth	M	
Trombone	gold/ orange	thick waves	smooth	M	
Classical guitar	turquoise green	thin waves	sharp	M	
Electric guitar – single notes	florescent pink, high notes red	pink curve	smooth	S	
Electric guitar – lots of chords	black and silver	black mess/grid and silver scrunches	rough	S	unpleasant
Organ	orange, sometimes pink or green	thick mist projected in front of me on a screen	misty	M	
Harmonica	turquoise green	thin waves	bumpy	M	
Flute	pink	long vertical wave	smooth	M	
Drums	black/ dark grey	thick curve	flat	S	
Castanets	yellow	triangles which appear then fade quickly	flat	M	
Xylophone	pink	short curve upwards	smooth	M	
Clarinet	blue	thin waves	smooth	M	

Inducer - Natural sounds	**Colour**	**Shape**	**Texture**	**Strength**	**Any other comment –** colour and shape vary a bit depending on actual sound
Carpentry sawing	light brown	big zigzags in a horizontal line which rises	rough	W	
Bird chirp	yellow – green tinge	triangles which move upwards and bounce into each other		M	colour varies sometimes depending on type of bird – e.g. high pitched birds are red
Doorbell	pink	thick horizontal line with a sharp peak	smooth	M	has a florescent quality like electric music
Car horn	red	small red bump	sharp	S	red sounds hurt
Screeching tyres	black/ dark grey	long vertical scratches which get smaller	rough	W	
Thunder	black	round circles like ripples which appear randomly then fade		S	
Waterfall	grey	continuous wide/thick horizontal line with little bumps	rough	M	ocean sounds similar
Wind	translucent	curves up and down and spirals	rough	M	
Airplane	black-brown	lots of large overlapping circles like ripples		S	like thunder but bigger circles which overlap more
Scream	red	sharp red peak which fades	sharp	S	
Whinney – horse	brown with green at the top	line curves up smoothly with green at the top	smooth	M	green is like a violin
Dog bark	brown	small sharp rises	sharp	W	depends on the type of dog, monkey etc
Cat meow	red	line with small dips downwards	curved	W	
Monkey	red	small triangles and a line which rises in peaks	sharp	M	
Sheep/ goat	blue	crumpled line which rises	crumpled	M	
horse galloping	brown	lots of circles which are attached by a continuous thin line	softer	M	
cicadas	yellow	lots of tiny triangles in one space which vibrate	bumpy	M	
applause	grey	flat plates piled on top of each other	flat	M	

Inducer - Natural sounds (cont)	**Colour**	**Shape**	**Texture**	**Strength**	**Any other comment –** colour and shape vary a bit depending on actual sound
ambulance siren	red	thin red vertical line curving up and down	sharp	M	
bubbles	clear	small round circles close to each other		M	
fireworks	red and black	thick vertical line which gets smaller, then small circles		M	
electric sparks	red and turquoise, florescent	vibrating coils	sharp	W	
typewriter	yellow	lots of triangles appearing then fading quickly	soft	M	

Inducer – Emotions (cont)	**Colour**	**Shape/ Movement**	**Texture/ Temperature**	**Strength**	**Location in body** (they are all located in my head as well)	**Any other comment**
calmness acceptance contentment patience peace comfort	pale yellow	curves like sand dunes	lots of little bits (like grains of sand) moving slowly together	S	in my head	I get this image when I meditate; I associate it with the texture/ taste of milk
pleasure amusement delight enthusiasm gladness gratification happiness joy, love, glee zest	pink, sometimes bits of orange and yellow; zest has streaks of gold too	wide horizontal waves rising upwards	the waves are a bit translucent/ misty – your fingers would go through if you tried to touch them; temp is warm	S	projected in front on a screen	like letter e
anticipation hope desire lust yearning euphoria ecstasy elation	darker pink	thin wave rises up to a sharp peak (then drops suddenly)	waves seem like floating liquid – like the sweet juice in your mouth when you're eating a toffee	S	projected in front on a screen	
ambivalence apathy boredom	grey and yellow	flat grey space with tinges of yellow	a bit cotton woolly like 'w' – plain and soft	W	projected in front on a screen	

Inducer – Emotions (cont)	**Colour**	**Shape/ Movement**	**Texture/ Temperature**	**Strength**	**Location in body** (they are all located in my head as well)	**Any other comment**
anxiety apprehension nervousness suspense worry fear	blue and red; fear has a bit of green	blue mist with red coils which tighten, enlarge and merge together as anxiety increases	blue mist is like small water droplets or dust; coils are fluid	S	projected in front on a screen	
panic shock alarm terror	dark red, little bit of blue	red coils joined together with bit of blue showing in background	red is thicker and congealed with dark spots like blood	S	projected in front on a screen	
confusion agitation impatience irritability angst annoyance discontentment	yellow and grey/ black	yellow curls in background with grey streaks which get darker as agitation increases	yellow cotton wool texture, almost itchy; grey streaks have consistency of tar or treacle – dark, sticky and fluid	M	projected in front on a screen	
anger rage negativity hate	black and red	black background and red coils	course texture like steel wool	M	projected in front on a screen	
depression grief despair	black and purple	tight black grid with shadow of purple	mainly plain and flat with little sandpaper bumps and thin dark lines	S	in my head	
emptiness	clear and blue	cold clear mist with tinges of blue	misty like water droplets	S	an open space inside my body replacing lungs and stomach	like zero

Inducer – Emotions (cont)	**Colour**	**Shape/ Movement**	**Texture/ Temperature**	**Strength**	**Location in body** (they are all located in my head as well)	**Any other comment**
sadness unhappiness sorrow melancholy	yellow and green	soft mist which rises upwards slowly	fine mist like water droplets; cool and fresh	M	projected in front on a screen	
nostalgia homesickness loneliness vulnerability	clear with tinge of orange	clear vertical thread which vibrates/ pulses	smooth and sinewy like a tendon	S	in front on my body: I feel as if I could hold onto it in my hand and could choose to let go or snap it	
pain suffering	red, sometimes blue – but only ever one colour	red coils, spikes, waves or tiny spots (depends on the type of pain)	depends on type of pain – thick congealed coils, misty waves, sharp spikes	M	in the place which hurts; often travels in waves up my body to my head	
guilt regret remorse	dark khaki green – yellow with bits of black	small dark round blobs which float in a thick green liquid	blobs are three dimensional, curved like blood cells; liquid is thick and gluggy	S	in my stomach	like letter q
disgust	dark khaki green	thick liquid	thick gluggy liquid	S	in my stomach	
horror	dark khaki green with streaks of red	thick liquid; thick red streaks	thick gluggy liquid; streaks are like liquid floating in air	M	in my stomach	
resentment contempt bitterness	black-green and red	black-green mist with small thin red streaks like spider-threads which move	plain black-green mist; thin streaks are fragile, like liquid floating in air	M	projected in front on a screen	

Inducer – Emotions (cont)	**Colour**	**Shape/ Movement**	**Texture/ Temperature**	**Strength**	**Location in body** (they are all located in my head as well)	**Any other comment**
jealousy envy	lime green	mist	plain and misty	W	projected in front on a screen	
embarrassment humiliation shame	bright orange	mist	plain and misty	W	around the outside of my whole head	
kindness compassion friendship gratitude	pink and yellow	swirls/ misty	soft and fluffy	W	in my head	
honour courage confidence pride	bright yellow, bit of orange	tall thick tower	hard, solid, smooth	W	in my head	
doubt inadequacy shyness	pale yellow	thin vertical thread	smooth and fragile	W	in my head	
pity	red	thin thread	smooth and fragile	W	in my head	
surprise alertness	bright yellow	flat	plain surface	W	in my head	
modesty humility fanaticism awe	no colour/ shape/ texture					