MENTAL IMAGERY IN SYNAESTHESIA

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ABSTRACT

The current thesis addressed the question of whether an internally generated mental image can elicit a concurrent in grapheme colour synaesthesia; although there is experimental and anecdotal evidence that this is the case, to date this had not been systematically explored. As there are purportedly distinct object-based and spatial-based imagery processes it was necessary to explore the role different imagery processes may play. In Experiment 1 synaesthetes and matched control groups completed a grapheme-based object-imagery task against congruently and incongruently coloured backgrounds. Four synaesthetes, but none of the control groups, showed an effect of colour on task performance. In Experiment 2 and 3 synaesthetes (and matched controls for Experiment 2) completed a grapheme-based spatial-imagery task, with either the stimuli or background colour manipulated as before. In each experiment colour was found to interact with grapheme presentation format for two different synaesthetes. Experiments 1-3 therefore provided support for the idea that an internally generated mental image can elicit a concurrent. Importantly, the results suggested a difference in the way the concurrent generated from object or spatial imagery processes influenced task performance. Consequently Experiments 4 and 5 used a battery of comparable imagery tasks that had either an object or spatial rate-limiting imagery process. Manipulation of the task background colour again showed the variety of effects the concurrent generated with these different imagery processes can have on task performance. Overall the results of these experiments suggest that a concurrent can be elicited from both object and spatial imagery processes; important individual differences were found, and individual performance varied between tasks, suggesting the possible role of strategy effects. Models of synaesthesia need to be able to explain these differences and further studies are needed to address this issue of task approach.

Chapter 1 – Literature Review

1.1 – Overview of thesis

The human sensory system works in such a way that for the vast majority of the population, a sensory stimulus presented in one modality will generate the perception of that stimulus within the same sensory modality. For example, a particular auditory stimulus will be perceived as a specific sound, such as the sound of a baby crying. However, for some individuals it is not as straightforward as this; in addition to the typical sensory sensations being elicited from certain stimuli, additional sensations are reported. The auditory stimulus, in addition to being perceived as a baby crying, may also generate the perception of visual shape or colour. The term '*synaesthesia*' has been used to describe this perceptual phenomenon, wherein the attributes of certain sensory stimuli elicit additional sensory experiences (Galton, 1880). Synaesthesia can be either 'acquired' (for example through brain-damage (Armel & Ramachandran, 1999), the consumption of hallucinogenic drugs (Shanon, 2002), or through meditation (Walsh, 2005)), or it can be a 'developmental' condition being present since early childhood in otherwise typical individuals.

In developmental synaesthesia, these additional sensory experiences occur without any extra effort, and can be between or within sensory modalities. Documented examples of the inter-modal types include sound-colour synaesthesia (Ward, Huckstep, & Tsakanikos, 2006) and lexical-gustatory synaesthesia, in which certain words induce particular tastes (Ward & Simner, 2003). Intra-modal synaesthesia usually involves the visual modality. With the example of grapheme-colour synaesthesia (the focus for this thesis), individuals experience additional colours in response to letters and numbers (graphemes), with the grapheme being referred to as the '*inducer*' and the colour as the '*concurrent*' (Grossenbacher & Lovelace, 2001). For example, the letter 'A' presented in a black font may generate a red concurrent, or the digit '7' may elicit a green concurrent. It has been estimated that approximately 1-2% of the general population experience grapheme-colour synaesthesia (Simner et al., 2006) which is thought to be one of the more common variants of the many reported types (Day, 2005). Accordingly, it has become one of the most thoroughly studied forms.

Much of the available research on grapheme-colour synaesthesia has focused on the nature of the concurrent, and first this chapter will provide an overview of what is known about this colour experience from both psychophysical and neuroimaging studies. Whether the concurrent has similar perceptual qualities to 'real' colour, or is simply a semantic association, has important implications. The nature of the concurrent is initially important for the establishment of synaesthesia as a genuine perceptual phenomenon. Furthermore, it is important for our understanding of the neuronal processes involved, as well as the potential implications this has for theories of typical cognition. Equally, our understanding of the nature of the inducer is important in developing a neurocognitive model of grapheme-colour synaesthesia, and this will be the second focus of this chapter. Research has focused on the role of visual processing, and the extent to which a visual representation of the inducer needs to be processed for the concurrent to be elicited. Additionally, research has started to address the issue of whether the inducer needs to be visually processed to elicit the synaesthetic concurrent. Some research suggests that the external presentation of the inducer is not a necessity, and that the mere concept of the inducer may be sufficient.

In relation to the potential need for the external presentation of the inducer, one aspect that has not yet been systematically addressed is whether an internally generated mental image of an inducer can elicit a synaesthetic concurrent. To date, experimental studies have mainly used external presentations of graphemes (either visually or aurally) and have explored various manipulations of the external presentation format. There are a few studies that have used the concept of the inducer, and have suggested that the concept is sufficient to elicit the concurrent. Additionally there are anecdotal reports in the literature that imagining an inducer elicits the concurrent. However there is no empirical evidence that this is the case, and as such models of grapheme-colour synaesthesia could potentially be incomplete if they only refer to an externally presented grapheme. The mental imagery literature provides a wealth of studies that add theoretical support to the idea that a mental image of a grapheme might elicit a concurrent, as mental imagery is thought to involve many of the same neural pathways as visual perception, including areas in the early visual cortex. The current thesis is therefore an attempt to explore the possibility of eliciting synaesthesia from a mental image of a grapheme, and the role that purportedly different imagery processes may play in that process.

1.2 - Research concerning the concurrent (the synaesthetic colour)

An individual with grapheme-colour synaesthesia (a ‘synaesthete’) typically describes having the additional sensory colour experiences since early childhood (Grossenbacher & Lovelace, 2001). These are usually highly specific colours which are elicited involuntarily when presented with particular graphemes. Synaesthetes generally report that the concurrent experience is simultaneous with the inducer presentation, and this has been supported by event-related potential (ERPs) studies showing the rapid onset of the concurrent (Beeli, Esslen, & Jancke, 2008; and see description of study in Sagiv & Ward, 2006). With regards to the subjective nature of the concurrent, a synaesthete, referred to as AED, describes how she experiences all achromatic text as having additional colours overlaid on the surfaces of the letters or numbers (Witthoft & Winawer, 2006). Similarly, a synaesthete referred to as C describes how when shown a black ‘4’, for example, she sees a blue concurrent as an overlay on top of the printed ‘4’ (Smilek, Dixon, Cudahy, & Merikle, 2001). A slightly different experience is described by other synaesthetes, such as Tyler’s description of his own synaesthesia in which he states, “when I see the number 3, for example, it does not appear in colour on the page. But when I think of the number three, I image the Arabic digit projected into dark space with an explicit golden-yellow color spread around it, as though projected by a spotlight” (Tyler, 2005, p. 34). Researchers have therefore suggested that there are two broad types of grapheme-colour synaesthesia, based on the spatial location that the concurrent is experienced in, with the former type being referred to as ‘projectors’ and the latter as ‘associators’ (Dixon, Smilek, & Merikle, 2004). Although there is a debate about the reliability of these subjective reports (Edquist, Rich, Brinkman, & Mattingley, 2006), and whether there are distinct behavioural patterns on certain perceptual tasks (Dixon, Smilek, & Merikle, 2004; Ward, Li, Salih, & Sagiv, 2006), these contrasting subjective reports of the concurrent immediately highlight the heterogeneous nature of the synaesthesia population.

The actual inducer-concurrent pairings are often reported to vary a great deal between individual synaesthetes, so while the letter “F” might be green for one synaesthete, it may be bright pink for another. Importantly however, many studies have found that within the same synaesthete the pairings are relatively stable over time. This internal reliability of the inducer-concurrent pairings was initially presented as objective evidence of the genuineness of the phenomenon (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Baron-Cohen, Wyke, & Binnie, 1987). In what has essentially become referred to as the gold standard “Test of Genuineness” (ToG), synaesthetes are presented with a list of graphemes, words, and non-words, and are asked to report the synaesthetic concurrents for each. Their consistency in choice is then re-tested some time later, without prior warning (usually after three to six months). Synaesthetes typically have almost-identical pairings over the two tests, with the consistency averaging around 92%, whereas non-synaesthetes with the same colour-choice paradigm, but with prior warning of a re-test only one to two weeks later, have an average of 35-38% consistency (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Simner et al., 2005).

As a possible consequence of the subjectively-simultaneous and consistent dual-colour experience, the concurrents have been shown to be difficult to ignore, even when this is at the detriment of task performance. A variant of the Stroop paradigm has been used to illustrate this (Elias, Saucier, Hardie, & Sarty, 2003; Mattingley, Rich, Yelland, & Bradshaw, 2001; Mills, Boteler, & Oliver, 1999; Odgaard, Flowers, & Bradman, 1999; Palmeri, Blake, Marois, Flanery, & Whetsell, 2002; Wollen & Ruggiero, 1983). In these studies synaesthetes have been visually presented with coloured graphemes, and asked to name the visual colour of each grapheme. When the grapheme colour does not match the colour of the concurrent experienced with that particular grapheme, synaesthetes are inhibited in their colour naming response time. In comparison, non-synaesthetes show no such difference. This has been interpreted as showing the interference caused to the synaesthetes' ability to name the visual colour of a grapheme when it is presented in a colour that is incongruent with the synaesthetic colour elicited by that grapheme (in comparison to when the colour is congruent, or in baseline non-graphemic conditions).

The basic synaesthetic Stroop paradigm does not demonstrate the perceptual qualities of the concurrent; the interference found with the Stroop paradigm could be happening at a conceptual rather than perceptual level of processing (MacLeod, 1991), as the interference could occur if the concurrent was simply a semantic association with a particular grapheme (Palmeri, Blake, Marois, Flanery, & Whetsell, 2002). However, various perceptual paradigms have been used throughout the synaesthesia literature to explore the extent to which the concurrent is perceptually, in addition to subjectively, similar to 'real' colour. The term 'real' colour refers to the typical colour experience caused by visual sensory receptors receiving different light wavelengths reflected from external stimuli. Synaesthesia researchers have adapted perceptual paradigms used within the field of visual perception research to assess the ‘perceptual reality’ of the internally generated colour experience of the concurrent, which occurs without the usual external stimulation of the sensory receptors.

One of the ways the concurrent has been explored is by using what is known about ‘real’ colour processing to see whether concurrents elicited by achromatic graphemes could be shown to have a similar effect on task performance as ‘real’ colours would. For example, as a surface feature, ‘real’ colour is thought to assist with figure-ground segregation, so that objects can easily be distinguished from the background. Researchers have used this conjecture to assess whether a concurrent elicited from an achromatic grapheme would also result in the facilitation of distinguishing an object from its background (Hubbard, Arman, Ramachandran, & Boynton, 2005; Palmeri, Blake, Marois, Flanery, & Whetsell, 2002; Ramachandran & Hubbard, 2001a). To this end, Ramachandran and Hubbard (2001a) conducted a series of experiments on two synaesthetes (and matched controls) using modified versions of established perceptual tasks. One such task was the embedded figures task, in which participants were briefly presented with a display of achromatic graphemic stimuli, containing target graphemes and distractor graphemes. They were asked to search for the shape of a figure that was made up from the distribution of the target stimuli (e.g. a set of ‘4’s forming the shape of a triangle distributed amongst distractor ‘5’s). From the brief stimulus displays the synaesthetes were significantly more accurate at correctly detecting the shape of the target graphemes embedded within the distractors. The authors suggested that this was because the synaesthetes, but not the controls, could use their concurrents to detect the shape formed by the target graphemes at a faster rate than non-synaesthetes, who simply perceived the stimuli as achromatic.

Another paradigm used to explore the perceptual qualities of the concurrent was a variation of the crowding task (Hubbard, Arman, Ramachandran, & Boynton, 2005) in which participants were required to identify an achromatic target grapheme presented in the periphery of their vision that was flanked by distractor graphemes. Typically, non-synaesthetes find accurate target identification difficult, due to the presence of the distractor graphemes. However, when individual synaesthetes were compared to their matched controls, three of the six synaesthetes tested showed more accurate achromatic target grapheme identification. Ramachandran and Hubbard (2001a) again suggested that the synaesthetes were using the colour of the concurrent elicited by the target grapheme to distinguish it from the distractor graphemes (which had a different coloured concurrent). This colour-facilitation has also previously been shown with some non-synaesthetes when differently coloured target and distractor graphemes were used (Kooi, Toet, Tripathy, & Levi, 1994).

The similarities between ‘real’ colour and concurrents have also been explored using visual search paradigms, where achromatic target and distractor graphemes were placed on a background colour that was either congruent or incongruent with the synaesthetic concurrent elicited by the target grapheme (Smilek, Dixon, Cudahy, & Merikle, 2001). In this single case study the synaesthete (and seven matched controls) had to locate one of two possible achromatic target graphemes amongst achromatic distractor graphemes. When the target grapheme was placed on a background that was congruent with the concurrent colour, the synaesthete was significantly slower to detect the target than when the background was incongruently coloured (and there was no difference for the controls). The authors proposed that this “congruency effect” was due to a difficulty in segregating the digit from the background when the ‘real’ colour of the background matched the synaesthetic concurrent elicited by the digit, as the colour of the concurrent produced a ‘camouflage effect’. This illustrates a potential interaction between the synaesthetic colour induced by the grapheme and the ‘real’ colour of the background, in the same way as a coloured digit would be difficult to locate if it matched the colour of the search background. Although this finding has since been replicated with another synaesthete (Smilek, Dixon, & Merikle, 2003), other research groups report that they have been unable to replicate it (Blake, Palmeri, Marois, & Kim, 2005; Sagiv, Heer, & Robertson, 2006). Blake et al (2005) found no effect of background colour for speed or accuracy on a vowel/consonant judgement task for achromatic characters. Interestingly, using a similar visual search task as Smilek et al, Sagiv et al (2006) found the opposite effect of background colour on letter detection, with the synaesthete they tested being faster when the background colour was congruent with the target letter rather than incongruent. These mixed results therefore highlight that the processing of the concurrent may differ across individual synaesthetes, to the extent that congruent and incongruent background colours can have no effect, or either facilitate or hinder performance on a visual search task. The reasons for this are not yet clear, although it could be due to task demands (i.e. making vowel/consonant judgements versus visual search, or searching for letters versus searching for digits) or differences between the synaesthetes, once again illustrating the heterogeneity of the synaesthete population.

Overall, it appears that for most synaesthetes, performance on a perceptual task can be affected by the concurrents elicited from the achromatic graphemes, in a very similar way as would be expected if the graphemes presented in the tasks were differently coloured. This supports the premise that concurrents have very similar functional qualities to ‘real’ colour. Following on from this, research has also explored whether there is evidence of concurrents being processed at the same stages in the visual processing stream as ‘real’ colours, using both behavioural and neuroimaging techniques. Again, previous research findings about ‘real’ colour processing have been used to assess the perceptual reality of concurrents. Studies of damage to the brain (Zeki, 1990) and neuroimaging studies (Zeki et al., 1991) have found that after passing through the colour receptive cells of the retina, externally presented ‘real’ colour is further processed in extrastriate regions of the visual cortex, in an area referred to as V4. One of the proposed functions of the processing in this area is to achieve ‘lightness constancy’, so that objects are perceived as the same colour when viewed under different lighting conditions (Zeki, 1983). This has been demonstrated with the non-synaesthete population with lightness constancy illusions, in which pictures of stimuli with identical lightness, but located in what appear to be different lighting conditions (i.e. one is in full light, and one is in a shadow) are perceived to have differing levels of lightness, despite the lightness being held constant (Adelson, 2000). With regards to synaesthesia, the concurrent, unlike real colour, is not externally presented to the visual system, and so Witthoft and Winawer (2006) explored whether the concurrent would also be processed at this early stage in the visual system. They hypothesised that if this was the case, then a synaesthete’s subjective rating of the brightness of a concurrent elicited from an achromatic grapheme embedded in a ‘shadow’ part of a lightness constancy illusion would be rated as less bright than a concurrent elicited from the same achromatic grapheme in the ‘light’ part of the illusion. To this end, they used the “Checkershadow Illusion” (Adelson, 2000) in which a picture is shown of the target stimuli placed on a checkerboard, either in the shadow of a large object or not in the shadow. Their single-case study found that the synaesthete’s perceived brightness of the concurrent was significantly affected by the grapheme’s apparent illumination. The authors suggested that this supports the idea that the concurrent was processed at an early stage of the visual processing stream, prior to the processing of lightness constancy. The results suggest that the brightness of the concurrent colour was adjusted by the same constancy mechanisms as “real” colour, and consequently that the concurrent was processed as a part of the visual scene.

Further evidence that concurrents are processed at the early stages of colour processing can be found with a study exploring the potential interaction between the concurrent and ‘real’ colour. Kim et al (2006) proposed that if concurrents are processed as ‘real’ colours then there would be evidence of an interaction between concurrents and ‘real’ colours with perceptual grouping paradigms. They tested this hypothesis with two well-established perceptual grouping paradigms that are known to show the effect of ‘real’ colour on grouping over time (the bistable apparent motion paradigm) and grouping over space (with the binocular rivalry paradigm). Research using the bistable apparent motion paradigm with the general population has shown that when quickly presented with two static ‘frames’, which contain stimuli in different positions, participants perceive the smooth movement of these stimuli from their first position in Frame 1 to their second position in Frame 2, rather than perceiving the two static frames they were shown (Wertheimer, 1912, cited in Kim et al, 2006). The direction of the movement of the stimuli is found to be ambiguous when the stimuli are an equal distance apart, but by adding a feature such as colour to the stimuli, this ambiguity disappears (Green, 1989, cited in Kim et al, 2006). Kim et al adapted this paradigm, so that in Frame 1 participants were shown achromatic graphemes. In Frame 2, when the stimuli were in different locations, rather than using achromatic graphemes, the stimuli were non-inducer coloured stimuli. By manipulating the colours of the non-inducer stimuli in Frame 2 to be congruent or incongruent with the concurrents elicited from the achromatic graphemes in Frame 1, the perceived direction of the apparent motion could be biased for the synaesthetes. These results therefore illustrate how synaesthetic concurrents interact with the ‘real’ colour, as if they were ‘real’ colours.

Kim et al’s (2006) second experiment used binocular rivalry to explore the interaction between ‘real’ and synaesthetic colours, and the effect this has on perceptual grouping over space. With binocular rivalry, one image is presented to one eye, while a different image is simultaneously presented to the same corresponding region of the other eye, typically resulting in alternations in perception between the two images (see Blake & Logothetis, 2002 for a review). Occasionally, rather than switching between images, a blending or mosaic of the images is perceived, and this is referred to as ‘mixed dominance’. This grouping together of the visual features across the images is more likely when similar image features are distributed between the rival images (Kovacs, Papathomas, Yang, & Feher, 1996). Importantly colour, as a visual feature, has been shown to promote perceptual grouping over space in binocular rivalry (Kim & Blake, 2004). Consequently, by manipulating the 'real' and synaesthetically induced colours in pairs of rival images, Kim et al (2006) were able to show that there was a strong tendency to group 'real' and synaesthetic colours together, in the same way as there was to group two identical 'real' colours together.

Another way of exploring whether concurrents are processed at the early stages of the processing stream has been to explore whether concurrents, like 'real' colours, are processed in the colour-opponent channels (Nikolić, Lichti, & Singer, 2007). At the early stages of visual colour processing there is a colour-opponency found with hue-selective cells in the colour specific areas of the visual cortex. At this early stage of colour processing, neurons have been found to have colour opponent receptive fields. This means that neurons excited by one band of wavelength are also inhibited by another, and vice versa; this results in green and red opponent colour channels, and blue and yellow opponent colour channels (Chichilnisky & Wandell, 1999; Hubel & Livingstone, 1987; Hurvich & Jameson, 1957; Zeki, 1980). Nikolić et al (2007) therefore hypothesised that if synaesthetic colours share perceptual qualities with 'real' colours, and are processed by these opponent channels, there would be evidence of more interference between a synaesthetic colour and 'real' colour when they shared the same colour channel than when they did not. They tested this hypothesis with a variant of the Stroop paradigm. As with previous synaesthetic Stroop studies, synaesthetes (N=6) and matched controls (N=12, 2 per synaesthete) were presented with coloured graphemes and asked to name the visual colour. The visual colours were manipulated so that they were congruent or incongruent with the synaesthetic concurrent, but importantly there were two different incongruent conditions. The first involved an incongruent colour that was 'opponent' to the synaesthetic colour, with the idea that it would use the same colour channel as the synaesthetic colour. For example, if red was the congruent colour, then green would be the opponent colour. The second was 'non-opponent', so that the colour was processed by a different channel to the synaesthetic colour, for example yellow. The usual congruent-incongruent interference was found, but in support of their hypothesis, the difference between the two different incongruent conditions was also significant, with greater interference shown in the incongruent-opponent condition. The authors used this interference, which was found for all six synaesthetes tested, to argue that synaesthetic colour and 'real' colour were processed in the same colour channel, resulting in the observed pattern of interference.

In addition to the grapheme-colour Stroop test, Nikolić et al (2007) conducted an object-colour Stroop test to add further support to the idea that the synaesthetic interference was at a perceptual level of processing rather than conceptual. Instead of naming the colour of graphemes, the same participants were asked to name the visual colour of recognisable objects (e.g. a lemon). As before, the colour of the object was manipulated so that it was congruent (a yellow lemon), incongruent-opponent (a blue lemon, as blue uses the same colour channel as yellow), or incongruent non-opponent (a red lemon). They found that although there was a significant difference between the colour conditions, the difference between the two incongruent conditions was very small and showed the reverse opponency effect to that found with grapheme-colour Stroop test. The authors suggested that this difference between the grapheme Stroop and object Stroop tasks supports the idea that semantic shape-colour associations use different mechanisms to synaesthetic grapheme-colour associations. Furthermore, the difference between the opponent and non-opponent naming times for the synaesthetes with the grapheme Stroop suggests that these grapheme-colour associations are likely to make use of neurons at an early stage of visual processing, where colours are processed by opponent colour channels.

Since the synaesthetic concurrent is perceptually very similar to 'real' colours, with the concurrent having an impact on both cognitive and perceptual tasks, there is also the possibility that the synaesthetic concurrent might activate even earlier areas in the visual processing stream. This is because in addition to neural messages going "forwards" in the visual processing stream, there is also substantial message "feedback", from higher visual areas to primary visual cortex, and also from primary visual cortex to earlier areas such as the lateral geniculate nucleus (LGN) in the thalamus. The LGN is a structure between the retina and primary visual cortex that directly receives information from the retina through the optic nerve. It also receives feedback information from the primary visual cortex, which in turn can influence the subsequent information sent forwards from the LGN (Sillito & Jones, 2002). Consequently, this feedback in the neural circuitry at the very early stages of the visual processing stream means that the perception of 'real' colour can be affected by contextual influences. For example, colour perception has been shown to be affected by both the spatial context (e.g. nearby light) and the temporal context (e.g. prior exposure to chromatic light). In order to see whether there are possible lower boundaries on candidate structures involved in grapheme-colour synaesthesia, Hong and Blake (2008) tested how susceptible the concurrent is to these contextual influences on colour perception. They conducted experiments to see whether the concurrent could be affected by surrounding colours (spatial context), and whether prior exposure to the concurrent would affect the subsequent processing of 'real' colours (temporal context). Although manipulation of the brightness of surround-light levels (i.e. background colour) was found to influence the perceived appearance of 'real' colour, these manipulations were not found to affect the induced brightness of the concurrent colour. Additionally, previous and simultaneous exposure to synaesthetic colours was shown to not have an effect on the subsequent perception of real colours. Taken together these findings suggest that neural events at the very early stages of the colour processing stream do not contribute to the synaesthetic concurrent, and the authors concluded that the earliest possible area would be in the extrastriate visual areas. Therefore, unlike 'real' colour processing, which can be shown to feedback to the LGN, the processing of the concurrent seemingly did not result in this type of feedback, highlighting a difference between 'real' colour and concurrent colour processing.

In addition to the behavioural evidence suggesting the involvement of the early colour processing areas in the processing of the concurrent, there is also a growing body of neuroimaging studies which have explored this issue (Hubbard & Ramachandran, 2005; Nunn et al., 2002; Sperling, Prvulovic, Linden, Singer, & Stirn, 2006). In relation to the visual perception of 'real' colours with the non-synaesthete population, neuroimaging studies have found that certain early visual areas are activated when presented with coloured stimuli or during colour-related cognitive tasks (the posterior fusiform gyrus or V4) and during tasks that require colour knowledge (medial ventral occipital regions) (Zeki & Marini, 1998). With regards to synaesthesia, researchers were therefore interested in finding out whether there would be increased activation of these early colour-selective regions when synaesthetes were either presented with spoken or visually displayed achromatic inducers. One of the first studies to explore the neural correlates of spoken word-colour synaesthesia used positron emission tomography (PET) to measure changes to regional cerebral blood flow (rCBF) when synaesthetes (N=6) and matched controls heard either spoken words or pure tones (Paulesu et al., 1995). As expected, when compared to the pure tone condition, the word condition showed greater activation for both groups in the language areas of the brain. Importantly there were also differences between the synaesthetes and non-synaesthetes, with the synaesthetes showing activation of visual associative areas, such as posterior temporal cortex and parieto-occipital junctions. However the study did not show any differences in activation in any of the early colour-selective visual areas. Therefore, although synaesthetes showed some atypical neural activity when presented with words that was associated with visual feature integration, there was no evidence of activity in the early colour processing regions that would support the perceptual reality of these colour experiences.

However, with the development of brain imaging techniques that have greater spatial resolution and sensitivity, such as functional magnetic resonance imaging (fMRI), activation of these early visual colour selective areas has subsequently been shown. For example, Nunn et al (2002) found increased activation of the colour selective regions (V4) when a group of 12 synaesthetes were presented with spoken words, compared to activation when listening to pure tones (no difference was found for matched controls). Importantly, further studies have since replicated this finding. Hubbard et al (2005) found increased activation in the colour-selective areas, when synaesthetes were presented with achromatic graphemes, compared to non-synaesthete controls. Sperling et al (2006) also found support for the hypothesis that the synaesthetic concurrent is accompanied by increased activation in the colour selective regions of the early visual areas, by comparing activation when synaesthetes viewed achromatic graphemes (inducers) compared to activation when viewing non-graphemic symbols (non-inducers). Greater activation in the colour-selective regions was found with the inducer condition for two of the four synaesthetes tested, again highlighting the heterogeneity of the synaesthete population.

The activation of these early visual areas involved in colour processing (in the absence of the normal external stimulation), raises the question of whether synaesthetic concurrents are comparable to other internally generated colours, such as in colour imagery or colour hallucinations. It has been suggested by some (e.g. Sperling et al, 2006) that synaesthetic colours are more similar to colours in visual hallucinations than colour imagery, for while colour hallucinations have been shown to activate early visual areas (ffytche et al., 1998), some research has suggested that colour imagery does not (Howard et al., 1998; Nunn et al., 2002). For example, in their study of the neural correlates of synaesthetic colour, Nunn et al (2002) included a group of non-synaesthetes who were trained to imagine the same word-colour associations as the synaesthetes. These trained controls showed no increase in activation of these early colour regions when imagining the colours in response to the words. Furthermore, with non-synaesthete participants Howard et al (1998) compared the neural activation during a colour imagery task (comparing colours of imaged objects) to a non-colour imagery task (judging difference between angles of clock hands), and did not find activation of the colour regions during the colour imagery task. Taken together these studies suggest an important difference between synaesthetic colour and imagined colours, and their approximation to veridical visual colour perception.

However, a recent study of the neural correlates of imagined and synaesthetic colours has highlighted the important limitations of these earlier studies (Rich et al., 2006). The Nunn et al study, for example, did not use a behavioural measure of the actual colour imagery; the trained controls may potentially have been thinking of the associated colour label, which could explain the lack of activation of the early colour regions. Similarly, Howard et al used a baseline comparison task (imagery of clock faces) that was very different to the colour imagery task, with different target stimuli and task demands. This might explain the lack of increased activation found in the colour processing regions, when activation from the two tasks was compared. In light of these problems, Rich et al (2006) conducted a study exploring the neural correlates of internally generated colour experiences that used a colour imagery task with a more comparable baseline task. Participants were shown greyscale pictures of two objects (e.g. a banana and a corn-on-the-cob) and the colour imagery task involved a colour-comparison of the objects (e.g. which is darker shade of yellow?) and the baseline task involved a size-comparison (e.g. which is larger?). The colour-imagery task therefore included a behavioural measure of the colour experience. In contrast to the previous findings, Rich et al found that the colour-imagery task activated the colour selective area (V4) for both synaesthetes and non-synaesthetes, supporting the idea that colour imagery activates early visual areas involved in colour perception. In the synaesthetic-colour task participants were shown displays of four inducer graphemes (congruent or greyscale), and the task to was detect a brief disappearance of one of the four stimuli. In contrast with the colour-imagery task, although the synaesthetes showed increased activation in an area associated with colour knowledge (left medial lingual gyrus) with the greyscale displays in the synaesthetic-colour task, significant activation of the early colour selective area (V4) was absent. These results therefore did not support the findings of Nunn et al, and suggest potential differences in brain areas used for different types of internally generated colour experiences.

The lack of activation of the early colour selective regions reported by Rich et al (2006), has also been found by other studies. One important interpretation of these conflicting results reflects potential differences between the synaesthetes and their synaesthetic experiences. For example, Hubbard et al (2005) have suggested that the difference could be due to differences in the strength of synaesthesia (as measured by the magnitude of the facilitation/interference of the concurrent on various perceptual tasks). In their study of brain-behaviour correlates of synaesthesia, which included both behavioural measures of the strength of the synaesthesia and neuroimaging, Hubbard et al (2005) found a strong correlation between strength of the synaesthetic experience and level of activation in the early visual areas. They therefore suggested that the degree of V4 activation could be associated with the individual’s strength of the synaesthetic experience, meaning that greater activation in these early visual areas is related to the perceptual quality of the concurrent, and the subsequent impact this has on perceptual tasks. Additionally, Sperling et al (2006) found significant activation in the colour sensitive area for only two of the four synaesthetes scanned. They suggested that a possible explanation for this inconsistency between synaesthetes could be a phenomenological difference in the way these synaesthetes described their colour experiences. The two synaesthetes showing significant activation described their synaesthetic experience as seeing "a screen in their mind's eye which gets completely coloured whenever seeing a letter inducing synaesthesia" (p.300). In contrast, the synaesthetes with no significant activation described their concurrents as "a transparent screen with a small and blurry but coloured version of the letter" (p.300). These distinct phenomenological reports therefore highlight a subjective difference in the experience of the concurrent, and importantly this difference is seemingly apparent in comparisons of the related brain activation. A potential explanation for conflicting results of the Rich et al (2006) study could therefore be that the concurrents for the synaesthetes tested were not strong enough to show activation in the early colour-selective areas, or that the synaesthetes had a type of synaesthesia more closely matching those reported by Sperling et al (2006) who did not show significant activation of the colour selective areas.

Another aspect of the concurrent that has been considered is what happens when a synaesthete is presented with an incongruently coloured grapheme. For example, a study exploring the neural correlates of looking at incongruently coloured inducers compared synaesthetes' neural activity when presented with incongruent graphemes to activation found with achromatic graphemes (Weiss, Zilles, & Fink, 2005). Interestingly, this comparison showed that viewing incongruently coloured graphemes increased activation in an area of the brain thought to be involved in cognitive control processes (left dorsolateral prefrontal cortex). It was proposed that these cognitive control processes were activated to help resolve the perceptual conflict of looking at an inducer eliciting a synaesthetic colour that does not match the 'real' colour being visually perceived. The authors argued that support for this interpretation comes from other studies showing activation of this brain region to help resolve perceptual conflict. For example, activation of the dorsolateral prefrontal cortex has been found when non-synaesthetes are presented with an incongruently coloured object, such as a purple banana (Zeki & Marini, 1998), and other situations when there is a conflict of the senses (Fink et al., 1999). It therefore seems that the processing of the concurrent is again similar to the processing of 'real' colours, to the extent that when a synaesthete is presented with a grapheme in the 'wrong' colour there is a similar neural response, as well as a subjective response, as when presented with familiar objects that are incongruently coloured.

In addition to measuring changes in brain activation when viewing congruent and incongruent stimuli, differences in the physical and emotional reaction have also been explored. For example, pupil dilation is an involuntary part of the autonomic nervous system and previous research has suggested that increased dilation is a marker of the use of attentional resources (e.g. Hess & Polt, 1964; Just & Carpenter, 1993; all cited in Paulsen & Laeng, 2006). In relation to synaesthesia, a recent study has measured changes in pupil dilation when synaesthetes passively viewed congruently and incongruently coloured graphemes (Paulsen & Laeng, 2006). Pupil dilation was found to increase when synaesthetes viewed incongruently coloured graphemes in comparison to viewing congruent or achromatic inducers. Therefore, viewing an incongruently coloured inducer elicited a physiological response that suggested an increase in processing load. This adds support to the idea that viewing incongruently coloured stimuli activates cognitive control mechanisms (Weiss et al, 2005). A recent single-case study has also explored the possibility of an emotional reaction to incongruently coloured stimuli (Callejas, Acosta, & Lupianez, 2007). Synaesthetes were shown congruently and incongruently coloured words, and were asked to make a judgement about the emotional valence of that word. The results showed that when presented with an incongruently coloured positive word, the subsequent rating was more negative than when the same word was presented in congruent colours. For example, the word ‘love’ presented in an incongruent colour resulted in a more negative rating of the word than when it was presented in the congruent colour. The authors suggested that this demonstrated how being presented with an incongruently coloured word could elicit an affective reaction, as this affective reaction was shown to subsequently bias the synaesthete’s performance on the evaluation task. Therefore in addition to the cognitive and perceptual effects observed when there is a conflict between the ‘real’ colour and synaesthetic concurrent, both of these studies illustrate additional aspects of this conflict, adding further support to the idea that synaesthetic concurrents share many perceptual qualities with ‘real’ colours.

1.3 – Research concerning the inducer (the presentation of the grapheme)

Overall, from the research findings outlined in Section 1.2, when some synaesthetes are visually presented with a grapheme, a concurrent is elicited which is not only subjectively similar to perceiving ‘real’ colour but is seemingly processed in a very comparable way, in terms of its ‘perceptual’ qualities, and also at a neuronal level. A further question considered in the synaesthesia literature relates to the processing of the inducer, and at what stage in the processing of the inducer the concurrent is generated. An issue that arises is whether the processes involved in the generation of the concurrent from the inducer, are in any way different to the processes involved in typical visual perception; for example, are there differences in the processes involved in the perception of a green object to the generation of a green concurrent when a synaesthete sees the letter ‘F’. As an initial step in exploring these issues, it is important to consider the sequence of events that occur when a non-synaesthete visually perceives a grapheme, so that comparisons can then be made to the sequence of processes thought to occur when a synaesthete is visually presented with a grapheme which elicits a concurrent.

Following the geniculostriate pathway of visual processing, it is thought that after the cells in the retina have translated the light signals into neural signals, and these have passed through the LGN, the cells in the primary visual cortex produce a basic representation of features of the stimuli, such as edges of the grapheme being viewed (Mather, 2006). Researchers have found that the cells in this area of the visual cortex are retinotopically organised, so that the pattern of activation on the surface of the brain corresponds with the light activation pattern that hits the retina (Heeger, 1999). More complex features of the grapheme, such as shape and colour, are then thought to be processed in areas of the occipital cortex outside primary visual cortex, in the extrastriate cortex. Following this, it is posited that there are then two main neural pathways leading out of the occipital cortex, where the grapheme is further processed; the ventral system and the dorsal system (Ungerleider & Mishkin, 1982). Within the ventral system information about the object and its related properties are thought to be processed, leading to object recognition. With the example of graphemes, it has been proposed that grapheme recognition mostly takes place within the fusiform gyrus, located in the left hemisphere (Dehaene, Le Clec, Poline, Le Bihan, & Cohen, 2002). This area is also referred to as the ‘visual word form area’ (VWFA), and support for this has come from research showing that this area selectively responds to graphemes and common grapheme-patterns (Cohen et al., 2002), does not respond to pseudo-fonts (Price, Wise, & Frackowiak, 1996), and can be activated through the subliminal presentation of words (Dehaene et al., 2001). Activation in approximately the same area as the VWFA has been found with visually presented numbers (Pesenti, Thioux, Seron, & De Volder, 2000; Rickard et al., 2000), and visually presented numbers and letters can both be shown (with cortical surface electrodes) to activate the same distinct populations (Allison, McCarthy, Nobre, Puce, & Belger, 1994). This is important for grapheme-colour synaesthesia, as inducers can be both visually presented letters and visually presented numbers. Furthermore, research also suggests that this area is restricted to the visual presentation of graphemes, as activation in this area has not been shown to be a necessity for spoken word processing (Dehaene, Le Clec, Poline, Le Bihan, & Cohen, 2002).

When presented with a grapheme in the visual field, in addition to the ventral system processing ‘what’ the object is, the dorsal system is thought to process ‘where’ the object is; i.e. the spatial location of the object. The dorsal system leads from the occipital cortex into the parietal lobes, and it is within this system that spatially-selective attentional information is thought to be processed, allowing attention to be focused on one particular target object located in a visual scene. Research has shown that this spatial attention can be disrupted through neurological conditions such as in Balint’s Syndrome, which results from damage to both parietal lobes (Robertson, Treisman, Friedman-Hill, & Grabowecky, 1997). Studies of patients with Balint’s Syndrome can be used to demonstrate the role that this spatial attention plays in accurately binding together different visual features, such as colour and shape, into the perception of one object (Robertson, 1999). When viewing two differently coloured letters, such as a red ‘A’ and a blue ‘B’ under free-viewing conditions, patients with Balint’s Syndrome are likely to report seeing a blue ‘A’ and red ‘B’; the visual features of these stimuli have not been conjoined accurately, resulting in what are referred to as ‘illusory conjunctions’ (Friedman-Hill, Robertson, & Treisman, 1995). Although colour and shape are processed separately in the ventral system, it seems that visual feature-binding involves the dorsal system, and specifically processing within the parietal lobes. This can also be seen with experimental manipulation of healthy participants’ spatial awareness, in which illusory conjunctions are found when spatial attention is disrupted though very quick exposure to the red ‘A’ and blue ‘B’ (Treisman & Schmidt, 1982). Feature Integration Theory (FIT) therefore proposes that in typical visual processing, the different visual properties of an object (e.g. colour and shape) are initially processed as separate features in the ventral system, and then combined in perception with spatial attention integrating the features, so that they are perceived as one object (Treisman & Gelade, 1980). The role of the parietal lobes in typical feature binding has been further supported with studies in the non-synaesthete population that have applied Transcranial Magnetic Stimulation (TMS) to the parietal lobes (creating a 'virtual lesion'), which document the subsequent deficit in target location in visual search tasks that require the conjoining of visual features (Ashbridge, Walsh, & Cowey, 1997). There is therefore a body of research which supports the premise that both the dorsal and the ventral system are involved in accurate visual feature-binding.

In relation to grapheme-colour synaesthesia, researchers have tried to determine whether the feature-binding involved in synaesthesia requires the same involvement of the ventral and dorsal systems as found in typical feature-binding. One of the main ways this has been explored is to see whether spatially selective attentional mechanisms are required for the grapheme-colour binding found with synaesthesia (i.e. the binding of the concurrent colour to the inducer form). As noted by other researchers (Robertson, 2003; Sagiv, Heer, & Robertson, 2006), if these mechanisms were not required, then arguably it would be possible for the concurrent to be elicited pre-attentively (i.e. the concurrent could be elicited prior to conscious recognition of the grapheme), as focused spatial attention would not be a pre-requisite. Some behavioural studies, using the visual search paradigm, initially suggested that the concurrent could be elicited pre-attentively (Palmeri, Blake, Marois, Flanery, & Whetsell, 2002; Ramachandran & Hubbard, 2001a; Smilek, Dixon, Cudahy, & Merikle, 2001; Smilek, Dixon, & Merikle, 2003). In these visual search tasks, synaesthetes were better able to detect a target grapheme, placed amongst distractor graphemes, than non-synaesthetes. Often the synaesthetes subjectively reported that they became aware of the concurrent before seeing the grapheme; implying that the concurrent was elicited prior to recognition of the form. The behavioural findings from these visual search tasks were interpreted as evidence that the usual spatially selective attentional mechanisms were not required for the binding of the concurrent to the grapheme form, as the concurrent was seemingly able to guide focal attention.

However, subsequent studies using variations of the visual search paradigm have presented conflicting evidence (Edquist, Rich, Brinkman, & Mattingley, 2006; Laeng, Svartdal, & Oelmann, 2004; Sagiv, Heer, & Robertson, 2006). For example, a study that involved an achromatic visual search task and a chromatic visual search task with synaesthetes (N=14) and matched controls, did not find the expected 'pop-out' effect with the synaesthetes in the achromatic trials that had been found when the targets and distractors were displayed in contrasting visual colours (Edquist, Rich, Brinkman, & Mattingley, 2006). A possible explanation for the earlier conclusions came from careful analysis of data from a single-trial study which appeared to show pre-attentive colour-form binding; rather than the concurrent occurring pre-attentively, resulting in a 'pop-out effect', Laeng et al (2004) found that the fast response times only occurred when the target was within a few degrees of visual angle from the initial fixation point. Essentially, synaesthetes had been found to be faster than non-synaesthetes in visual search tasks because the colours induced by both the target and distractor graphemes allowed faster serial-searching, and so faster rejection of the distractors. This idea was further supported with the findings of a study that used non-graphemic distractors (Sagiv, Heer, & Robertson, 2006). If concurrents were elicited pre-attentively then one would expect faster search times for the synaesthetes, regardless of whether the distractors were graphemic or non-graphemic. However, the two synaesthetes tested showed no such advantage in target detection when compared to the non-synaesthetes, adding support to the premise that spatial attention is required for the binding of the concurrent to the grapheme form.

The role of spatially selective attentional mechanisms has also been explored by looking at the spatial focus of attention. Sagiv et al (2006) conducted an experiment that manipulated the apparent ‘spatial’ location of the inducer, so that the inducer was either inside or outside of a synaesthete’s focus of attention. This was to see whether a synaesthete’s performance on a dot colour judgement task would be affected by the relative location of an achromatic distractor grapheme. In each trial, two identical grey-scale digits appeared on the screen, either side of a fixation point; after 200ms a set of four coloured dots were added to the display that were either congruent or incongruent with the concurrent elicited by the digits. Participants were required to name the colour of these target dots. While the location of the digits were held constant across trials, the location of the dots varied so that they were either close to the fixation point, meaning that the digits were outside the ‘attentional window’, or the dots were in the periphery of the visual field, putting the digits inside the ‘attentional window’. The authors predicted that synaesthetes would be slower to name the colour of the dots when they were incongruent with the digits on the screen, due to interference from the colour of the concurrent elicited from the digits. Importantly however, they expected the magnitude of this interference to be affected by the relative location of the distractor digits (i.e. inside or outside the attention window). In support of this, the results showed that the interference was greater when the inducers were inside the window of visual attention, than when they were outside. From the results of this experiment, and those mentioned previously, Sagiv et al proposed that “attention plays a central role in integrating colour and shape in synaesthesia” (2006, p. 241), and so grapheme-colour binding can be seen to use similar mechanisms to those used in typical perception.

Further research to explore the role of attention in synaesthesia has manipulated the amount of perceptual processing of the inducer. The premise behind this research is that if attentional mechanisms are employed in the generation of a concurrent from an inducer, then manipulation of the focus of those attentional mechanisms would affect the generation of the synaesthetic concurrent. For example, the priming effect found with synaesthetes in a colour naming task, when the colours are primed with achromatic graphemes that elicit a congruent concurrent, is ‘eliminated’ with masking that results in the grapheme prime being processed but not at a conscious level (Mattingley, Rich, Yelland, & Bradshaw, 2001). The authors concluded that as the concurrent was not elicited, despite substantial processing of a stimulus that would normally act as an inducer, grapheme-colour binding is likely to occur after the completion of the initial grapheme-recognition processes. This provides support for the idea that concurrents cannot be elicited pre-attentively. However, this conclusion has been criticised, as it has been suggested that this result was more likely due to the level of the neural processing required for unconscious colour priming per se, rather than the lack of priming from the synaesthetic concurrent

(Johnson, Jepma, & de Jong, 2007). Studies have suggested that unconscious colour priming with externally presented ‘real’ colour with the non-synaesthete population involves neural activity in the primary visual cortex (Breitmeyer, Ro, & Singhal, 2004), and so occurs in an early stage of the visual processing stream. Consequently, as synaesthetic concurrents are elicited by the grapheme at a later stage of the visual processing stream, Johnson et al (2007) argued that synaesthetic concurrents are very unlikely to be available at the early processing level required for unconscious colour priming. They therefore suggest that Mattingley et al’s conclusion could be premature, as their findings may simply be a result of the method used.

In light of these issues, Johnson et al (2007) conducted a study using an attentional blink paradigm. This paradigm also modulates the amount of processing of visually presented stimuli but does not rely on unconscious colour priming to record whether unidentified graphemes can act as inducers. In the attentional blink paradigm two targets are presented in quick succession, resulting in the second target not being reported as it appears in the ‘attentional blink’ following the first target. Although this unreported second target is not consciously processed, there is evidence to suggest that it is processed up to the semantic level, as it has been shown to successfully prime subsequent word-target responses (Shapiro & Raymond, 1994, cited in Johnson et al, 2007). Johnson et al used achromatic inducers for the two targets, and found that in trials in which the second target was not identified, the synaesthetic concurrent from this ‘blinked’ target was still reported correctly at a significantly higher than chance level, by four of the ten synaesthetes tested. Therefore, using a paradigm that was not reliant on unconscious colour processing, these results add support to the idea that, for at least some synaesthetes, complete conscious recognition of an inducer is not essential for the synaesthetic colour to be elicited. The results suggest that although the level of processing of the grapheme was not enough to reach conscious awareness, there was enough processing for the subsequent synaesthetic concurrent to be induced. It therefore seems that Mattingley et al's (2001) findings may have been due to the method used, rather than the need for the synaesthete to be consciously aware of the grapheme-form. Importantly however, Johnson et al (2007) do not suggest that the binding of the concurrent to the grapheme happens pre-attentively, but rather that explicit recognition of the inducer is not always a requirement.

With regards to the processing of the inducer, it is important to also consider how the amount of attention given to the inducer might "prioritise perceptual input for further processing" (Mattingley, Payne & Rich, 2006, p.216). This has been addressed by looking at the effect of stimulus competition on the strength of the concurrent (Rich & Mattingley, 2003), and also by looking at the effect of reduced attentional resources on the strength of the concurrent (Mattingley, Payne, & Rich, 2006). In relation to stimulus competition, there have been anecdotal reports that using Navon-type figures, where small graphemes are used to make the shape of a different larger grapheme (resulting in a potential competition between the local and global grapheme), the concurrent elicited is dependent upon which grapheme attention is focused on (Palmeri, Blake, Marois, Flanery, & Whetsell, 2002; Ramachandran & Hubbard, 2001a). These subjective reports have subsequently been supported with an experiment that manipulated the visual colour of these local-global stimuli to see whether the concurrent elicited from the attended inducer would have greater interference with the ‘real’ colour than the concurrent elicited from the ignored inducer (Rich & Mattingley, 2003). In this study, synaesthetes and non-synaesthetes took part in a speeded visual colour-naming task, in which the visual colour was either congruent or incongruent with the attended grapheme. The results showed that a greater congruency effect was found when the visual colour was incongruent with the attended grapheme than when it was incongruent with the non-attended grapheme, thereby supporting the idea when there was stimulus competition, mechanisms of selective attention played an important role in the subsequent concurrent elicited. Therefore although the inducer is thought to elicit the concurrent without any voluntary effort (as described in Section 1.2 with the impact of the concurrent on cognitive and perceptual tasks) the focus of attention can be seen to be important.

Reducing the amount of overall attentional resources available to the synaesthete has also been found to have an effect on the salience of the concurrent (Mattingley, Payne, & Rich, 2006). By varying the amount of attentional resources available during a grapheme-prime task Mattingley et al showed that the congruency effect found was much greater when the synaesthetes simultaneously completed a ‘low-load’ attentional task than a ‘high-load’ attentional task. The attentional task involved identifying the larger of two gaps in a shape surrounding the grapheme prime; in the ‘low-load’ task the larger gap was relatively easy to discriminate and in the ‘high-load’ task it was more difficult. Mattingley et al suggested that these findings fit with Lavie’s (1995) account of the effect that a task’s attentional load can have on the perceptual processing of irrelevant stimuli. In Mattingley et al’s study (2006) the irrelevant stimuli would be the synaesthetic concurrents induced by the graphemes. Therefore, when the task had a low attentional load there was enough processing capacity available to allow perceptual processing of the inducer and concurrent. However, in the high-load condition the attentional resources were used up by the task demands, and so the irrelevant items could not be fully processed. These results again show the importance of attentional mechanisms to the generation of a synaesthetic concurrent, since if the concurrent was elicited prior to the allocation of focused attention, there would have been no difference in the congruency effect found with the different attentional-load conditions. Mattingley et al also suggested that these results could explain why research that uses an attention-demanding task can report little or no effect of the synaesthetic concurrent on task performance.

Further support for the role of spatially-selective attentional mechanisms in the concurrent-grapheme binding comes from research exploring the role of the parietal cortex in grapheme-colour synaesthesia. As outlined earlier, areas within the parietal cortex are thought to play an important role in the spatial processing involved in typical visual feature-binding (Robertson, 2003). In support of this, activation of the parietal cortex has been shown in various neuroimaging studies exploring grapheme-colour synaesthesia. For example, an fMRI study in which synaesthetes were visually presented with inducers and non-inducers found that synaesthetic concurrents were associated with enhanced activity in the left intraparietal sulcus (IPS) (Weiss, Zilles, & Fink, 2005). Weiss et al suggested that the activation they observed within the IPS illustrated the physiological basis of a key neural mechanism for grapheme-colour synaesthesia, and speculated that the activation was in the left hemisphere because grapheme processing is thought to be a left hemisphere function (Stephan et al., 2003). However, it should be noted that there is conflicting evidence about the question of laterality with synaesthesia. For example, Paulesu et al (1995) found that presenting synaesthetes with spoken words resulted in significant activation bilaterally in the superior parietal lobe, whereas Nunn et al (2002) found significant activation in the left angular gyrus, and Rich et al (2003) found activation in the right posterior parietal cortex. However, in support of the role of the left parietal lobe, a study using diffusion tensor imaging (DTI) to measure structural connectivity in synaesthetes' and non-synaesthetes' brains found that synaesthetes had increased connectivity not only around the location of the VWFA, but also around the left IPS and frontal lobe (Rouw & Scholte, 2007). This greater level of structural connectivity within the regions of the brain involved in colour-form binding can be used as support for the argument that this region is critical for synaesthetic binding.

The functional role of the parietal lobes in the generation of the synaesthetic concurrent has been illustrated with TMS studies. These have shown that following application of TMS to areas within the parietal cortex, the interference between the concurrent and real colour has less impact on task performance, suggesting that the mechanism causing that interference has been disrupted by the transient inhibition from TMS. For example, the interference in colour naming times on a synaesthetic Stroop task was significantly reduced in two synaesthetes after TMS had been applied to the right angular gyrus at the junction of the posterior IPS and transverse occipital sulcus (Esterman, Verstynen, Ivry, & Robertson, 2006). Importantly, this difference was not found when TMS was applied to the corresponding region in the left hemisphere, or to area V1. The authors concluded that this provided support for the functional role of this region in the spatial binding of the concurrent to the grapheme form. They also commented that the difference in hemispheres was consistent with research evidence from the non-synaesthete population which has suggested that the right parietal cortex is more important than the left in typical colour-form binding (Ashbridge, Walsh, & Cowey, 1997).

Importantly, this finding has been replicated and extended with a subsequent study showing disruption of grapheme-colour synaesthesia following TMS to the right posterior parietal cortex (Muggleton, Tsakanikos, Walsh, & Ward, 2007). Muggleton et al extended the findings of Esterman et al (2006) by applying TMS to more regions of the parietal lobe, and by using a more diverse sample of synaesthetes. Whereas Esterman et al had applied TMS to only one site within the parietal cortex, Muggleton et al additionally applied TMS to areas of the left parietal cortex that previous fMRI studies had implicated (Nunn et al., 2002; Weiss, Zilles, & Fink, 2005). However, a significant decrease in task interference was only found for the five synaesthetes when TMS was applied to the right parieto-occipital site. Therefore, like Esterman et al, the authors concluded that this reduction in task interference following TMS suggested that the mechanism that caused the interference had been disrupted, and that the mechanism was likely to be located within the right parieto-occipital junction. Additionally, Muggleton et al used synaesthetes that could be classified as both ‘projectors’ and ‘associators’. This was to explore Esterman et al’s speculation that the parietal lobes would be more likely to play a role when the synaesthetic experience involved the binding of the concurrent to a specific external spatial location (i.e. for projector synaesthetes who report seeing their concurrent as if it is externally located on the actual visual form of the grapheme) than when it is bound to an internal representation of the grapheme (i.e. associator synaesthetes). However, Muggleton et al found that applying TMS to the right parieto-occipital site disrupted the binding mechanisms for all of the synaesthetes, and so concluded that the region is important for binding the concurrent to inducers represented within both external and internal spatial reference frames.

This suggests that the binding of the concurrent to the visual form of the inducer does use typical binding mechanisms. There is behavioural evidence to support the role that the spatially selective mechanisms play in this feature-binding process, both in terms of generating the concurrent and in modulating the salience of the concurrent. Additionally, there is evidence to support the role of the parietal lobes in the binding of the concurrent to the grapheme-form, as has been shown with typical visual feature-binding. Following from this, as typical visual feature binding is thought to involve an interaction between the dorsal and ventral systems, it could be hypothesised that in addition to the spatial attention requirement, the processing of the visual form of the grapheme is also an important determinant of the generation of a concurrent. Consequently, researchers have explored whether it is the visual representation of the grapheme, which is processed at the earlier levels of visual processing (when the grapheme-form is initially processed) that initially elicits the concurrent, or whether it is generated from the semantic processing of the concept of the grapheme later in the visual stream.

There have been conflicting reports concerning the role that the visual processing of the grapheme-form plays in the generation of the concurrent. For example, it has been suggested that for most synaesthetes the font and case of the inducer have no impact on the colour experienced (Dixon, Smilek, Duffy, Zanna, & Merikle, 2006; Grossenbacher & Lovelace, 2001). This could therefore suggest that the visual processing of the inducer is not important because an uppercase 'A', for example, has a very different visual-form to a lowercase 'a'. However, it has also been reported that for other synaesthetes the case or font may have some effect on synaesthesia (Ramachandran & Hubbard, 2003b) with more prototypical fonts producing subjectively more vivid synaesthesia, and some synaesthetes describing experiencing less saturated colour with lowercase letters compared to uppercase letters (Ramachandran & Hubbard, 2003a). Empirical support for these observations comes from a single-case study of a synaesthete who has English as her first language, but also learnt Russian from a very young age (Witthoft & Winawer, 2006). Interestingly concurrents were developed for Cyrillic graphemes in addition to English graphemes. A comparison of the colours experienced for both sets of graphemes shows the importance of the visual form, as the Cyrillic characters with a similar visual form to the English characters had the same synaesthetic concurrent. Importantly, this was found to be the case even when the characters have very different meanings (an example given is the character 3, which is a digit symbol in English, but is a Cyrillic letter that makes a 'z' sound, like in the word 'zoo'). To further explore the role of the visual format of the grapheme, Witthoft and Winawer (2006) manipulated the font and case of both English and Cyrillic graphemes to see the subsequent effect on the saturation of the concurrent. Graphemes were presented in either Times or Sands font, and in upper and lower case. When presented in Times the saturation was found to be higher than Sands, and when they were in uppercase the saturation was higher then when in lowercase. An interaction was also found, so that the highest saturation was in Times and uppercase. The authors suggested that this may be because the graphemes appeared more prototypical in this format. A limitation of this study is that it is only a single-case study, but it does provide a clear example of how the visual format of the grapheme can be important for the subsequent synaesthetic concurrent.

A further study to explore the importance of the perceptual form of the inducer manipulated the contrast of the inducer, in comparison to its background, to see the effect on the reported strength of the concurrent, and the impact of the concurrent on perceptual tasks (Hubbard, Manohar, & Ramachandran, 2006). As noted by Hubbard et al, previous consistency studies have presented high-contrast graphemes; a black grapheme presented on a white background or vice versa. However, some synaesthetes report that the strength of the concurrent depends on the level of contrast between the grapheme and the background, with lower contrast resulting in a subjectively weaker concurrent. In order to verify this, in a single-case study Hubbard et al (2006) systematically varied the contrast level between the inducer and background whilst the synaesthete rated the strength of the resulting concurrent. As predicted, the strength was found to be related to contrast level. However, in order to provide more objective evidence, Hubbard et al also systematically varied the contrast level in perceptual tasks that have previously been used to show the perceptual qualities of the concurrent; ‘the embedded figures task’ and the ‘crowding task’ as used by Hubbard et al (2005). The results showed that performance on the embedded figures task was affected by contrast, although with the crowding task the contrast effect was not as strong. The authors used these findings to argue that the visual form of the inducer can be critical for the synaesthetic experience, and posited that for this particular synaesthete at least, the concurrent was elicited at contrast-dependent stages of visual processing. Hubbard et al proposed that the likely area was the grapheme-processing area within the fusiform gyrus, the VWFA. Importantly, the neural response of this area to graphemes has also been shown to be contrast-dependent in the non-synaesthete population (Mechelli et al, 2000; Avidan et al, 2002, both cited in Hubbard et al, 2006), suggesting that the changes in strength of the concurrent could be due to these similar changes in the neural response in the VWFA.

However, in addition to the studies that have manipulated the visual presentation of the inducer, some studies have manipulated the context of the inducer to show how the context, and not the visual form, can have an impact on the subsequent concurrent (Dixon, Smilek, Duffy, Zanna, & Merikle, 2006; Myles, Dixon, Smilek, & Merikle, 2003). Both Myles et al and Dixon et al have used a single-case study (with different synaesthetes) to show how presenting the same ambiguous graphemes in different contexts can affect the subsequent concurrent elicited. Myles et al (2003) presented a synaesthete with three ambiguous graphemes that could be interpreted as either digits or letters; for example a grapheme that could either be seen as a ‘2’ or a ‘Z’. Importantly, for the synaesthete that was tested, the concurrent elicited by a ‘2’ (green) was different to that elicited by a ‘Z’ (brown). They used the Stroop paradigm, presenting the ambiguous graphemes in either ‘letter’ or ‘digit’ trial blocks, in order to manipulate the context of the grapheme. When the ambiguous grapheme was interpreted as a number (‘2’) but coloured as a letter (brown) synaesthetes were slower to name the visual colour of the grapheme, reflecting the expected congruency (and vice versa when interpreted as a letter but coloured as a number). The results therefore provide some support for the idea that an ambiguous grapheme can elicit different concurrents depending on the context. However, this difference was only found for two of the three ambiguous graphemes used. Dixon et al (2006) have been able to replicate these findings, but with a different synaesthete, and using five ambiguous graphemes. Although they used the same Stroop-based colour naming paradigm, instead of creating the context by using separate letter and digit trial blocks, Dixon et al used a random presentation of letter and digit context, and created the sense of context by placing the ambiguous symbol within a string of letters or digits. For example, an ambiguous grapheme that could be interpreted as either a ‘5’ or an ‘S’ was placed within the digit string ‘34567’ or the letter string ‘MUSIC’. Dixon et al argued that this modification of the method made the context more salient. Both of these studies show how presenting the same visual form, but with different contextual meanings, a different concurrent can be elicited. Dixon and colleagues have therefore argued that it is the concept of the inducer (i.e. the concept of ‘5’ or ‘S’) that determines the generation of the specific concurrent, rather than the visual form.

Further support for the idea that the concept drives the synaesthetic concurrent rather than the visual form comes from studies showing that in the absence of the external presentation of the inducer, the concurrent can be elicited from the concept alone (Dixon, Smilek, Cudahy, & Merikle, 2000; Elias, Saucier, Hardie, & Sarty, 2003; Jansari, Spiller, & Redfern, 2006; Smilek, Dixon, Cudahy, &

Merikle, 2002a). In these studies synaesthetes were presented with a mathematical sum and then a coloured block, and their task was to name the visual colour of the block and then give the answer to the sum. For the synaesthetes, but not the matched controls, the naming time was slower for trials in which the colour patch was incongruent with the sum, and was faster when it was congruent. This congruency effect was found despite the fact there was no external presentation of the answer to the sum. The results have therefore been taken to imply that simply thinking of a concept of an inducer is enough to elicit the concurrent, as the congruency effect observed was similar to that previously found with synaesthetic Stroop studies in which the inducer was visually presented (for example Wollen & Ruggiero, 1983). As there was no external visual presentation of the inducer with the mathematical Stroop studies, but yet the concurrent was still seemingly elicited, further support is provided for the idea that it is not the visual percept of the grapheme that elicits the concurrent. Instead, simply thinking about the concept of the inducer can be shown to elicit the synaesthetic concurrent.

1.4: Models of synaesthesia

In an attempt to explain the causes of grapheme-colour synaesthesia, a debate has arisen in the literature concerning the probable neuronal architecture and processes involved. One of the main issues of contention is whether synaesthesia, of any type, arises due to additional neuronal connectivity between brain areas (the 'Hyperconnectivity Hypothesis'; Bargary & Mitchell, 2008; Ramachandran & Hubbard, 2001a; Rouw & Scholte, 2007) or whether it is due to a difference in inhibition processes in typically existing neuronal pathways, (the 'Disinhibition-Unmasking Hypothesis'; Cohen Kadosh & Henik, 2007; Cohen Kadosh & Walsh, 2006; Grossenbacher & Lovelace, 2001). However, the current thesis will more specifically focus on two models of grapheme-colour synaesthesia that attempt to describe the precise processes involved in the generation of a concurrent from the presentation of a grapheme; the cross-activation theory (Ramachandran & Hubbard, 2001a, 2001b) and the re-entrant feedback model (Smilek & Dixon, 2002; Smilek, Dixon, Cudahy, & Merikle, 2001). Importantly, these models do not dispute the perceptual nature of the concurrent, but rather they disagree about the representational level at which the concurrent is elicited; whether it is at a perceptual level early in the visual processing stream, or later with higher level conceptual representations. This question of whether the concurrent is elicited through the processing of the visual form or the conceptual meaning of the inducer has important implications for the neural architecture potentially involved in synaesthesia. Although neuroimaging studies have provided some information about the neural correlates of the concurrent, information about the sequence of processes involved is sparse. Consequently, the models, as described below, have mainly been developed with behavioural evidence concerning the key processes thought to be involved when a concurrent is elicited from a grapheme.

The cross-activation theory (Ramachandran & Hubbard, 2001a, 2001b) has argued that the representational level at which the concurrent arises is the percept, or visual form, of the grapheme. Specifically, proponents of this theory assert that the synaesthetic concurrent is elicited at an early stage of perceptual processing; through cross-activation between the two adjacent regions of the fusiform gyrus thought to be involved in both colour processing (V4) and visual recognition of graphemes (the VWFA). Thus, when visually presented with a grapheme, the processing of its visual form in the VWFA is thought to directly elicit the concurrent through cross-activation with the adjoining colour processing area, V4. This theory therefore assumes an anatomical difference between synaesthetes' and non-synaesthetes' brains, with additional cortical connectivity between the associated areas for the synaesthetes. Hubbard et al (2006) propose support for this theory from research concerning both the synaesthetic concurrent and the fusiform response to graphemes. For example, with regards to the concurrent, research indicates that the 'strength' of the concurrent (as shown by the relative behavioural advantage on perceptual tasks using achromatic graphemes) can be modulated by the visual processing of the inducer. As outlined in the earlier sections, this can been seen with Hubbard et al's (2006) study that suggests the concurrent is elicited at a contrast dependent stage, and also with studies indicating that the concurrent is processed at the early stages of the visual system (Kim, Blake, & Palmeri, 2006; Nikolić, Lichti, & Singer, 2007; Witthoft & Winawer, 2006). Furthermore, some neuroimaging evidence implies that the colour processing area of the fusiform is involved in the generation of the concurrent. In particular, indirect support for the cross-activation theory comes from the finding that, on an individual level, the degree of activation of this area relates to the 'strength' of the concurrent in behavioural tasks (Hubbard, Arman, Ramachandran, & Boynton, 2005). The response properties of the VWFA (as outlined earlier) suggest that this is the initial grapheme recognition area, and this can be seen to be consistent with the finding that more prototypical fonts elicit a stronger concurrent (Witthoft & Winawer, 2006), as the response of the VWFA may be stronger with prototypical examples, resulting in greater activation in the adjacent colour-processing area.

However, not all of the research outlined in the earlier sections supports the importance of the processing of the visual form, and consequently the re-entrant feedback model argues that the representational level at which the concurrent arises is a conceptual one, rather than perceptual (Smilek & Dixon, 2002; Smilek, Dixon, Cudahy, & Merikle, 2001). This alternative model posits that the concurrent is not elicited through direct cross-activation in the early stages of the visual system. Instead, the model proposes that the concurrent is elicited through disinhibited feedback, with cortical activity from the areas of the brain that process meaning feeding back to the earlier colour selective regions. Therefore, this model does not suggest an anatomical difference in brain structure, but a difference in inhibition of cortical feedback circuits. Specifically, Smilek and colleagues propose that the concurrent arises as part of the cyclical iterative perceptual processes, involving both feedforward and feedback connections between the anterior fusiform and posterior inferior temporal areas back to V4. According to this theory, when a “2” is initially processed in the early visual areas and grapheme recognition areas, information is fed forwards to the anterior fusiform areas where the concept of a “2” is evoked. In the early stages of the cycle they suggest that there might not be enough of a signal to elicit a conscious experience of “2” but the concept of a “2” would be more strongly activated than other graphemes, and so information about the concept of a “2” will be fed backwards to the earlier visual areas. In the case of a synaesthete seeing a “2” this is thought to also include colour information based on the meaning of the digit being fed back to the colour processing areas, eliciting the concurrent evoked by the concept of a “2” (e.g. ‘red’). The continual cycle of feedforward and feedback signals then continues until “the perception that gradually accrues over successive iterations will be that of a synaesthetically red 2” (Smilek & Dixon, 2002, p. 10). Consequently, grapheme-form is linked to meaning, and importantly, the re-entrant feedback model proposes that it is this concept of the grapheme which feeds back colour-information to the colour processing area, and the concurrent therefore arises from top-down mechanisms.

The re-entrant feedback model therefore argues that the processing of the concept of a grapheme is more important than the processing of the visual form. Support for this can be seen with both the Dixon et al (2006) and Myles et al (2003) studies, as outlined earlier, in which ‘context’ was shown to play a determining role in the concurrent experienced from an ambiguous grapheme. However, Hubbard et al (2006) have argued that this contextual modulation does not necessarily mean that there is not direct cross activation between the VWFA and the colour processing areas in the fusiform gyrus. They instead speculate that there could be top-down influences of the grapheme-meaning processing area, resulting in different changes of neural activity in the VWFA (i.e. perceiving an ambiguous grapheme as a ‘2’ or a ‘Z’), leading to different colour selective regions being activated (through direct cross-activation with the VWFA). In contrast, the re-entrant feedback model states that the colour information is fed back from the grapheme-meaning processing areas, rather than direct cross-activation between the VWFA and colour selective regions. However, as noted by Hubbard et al, due to the limitations of neuroimaging technology such as fMRI, previous studies have been unable to explore this possibility. They suggest that more recent developments with EEG or MEG should be able to explore this possibility as they have better temporal resolution.

Further support for the re-entrant feedback model has come from the mathematical Stroop studies, which ostensibly show that the mere concept of the inducer is enough to elicit the synaesthetic concurrent (Jansari, Spiller, & Redfern, 2006; Smilek, Dixon, Cudahy, & Merikle, 2002a). In these studies, simply thinking of an inducer as an answer to a sum, in the absence of the external presentation of that inducer, results in the apparent generation of the concurrent. Consequently, it would appear that visual processing of the inducer was not needed for the concurrent to be evoked. However, as noted by Hubbard et al (2006) and Jansari et al (2006), the results from these studies do not rule out the possibility that the synaesthete was actually imagining the inducer, and it was this internally generated mental image which elicited the concurrent. Indeed, synaesthetes often report using mental imagery of inducers in tasks that non-synaesthetes do not, for example using imagery-based memorisation techniques for phone numbers whereas non-synaesthetes typically report using auditory rehearsal (Yaro & Ward, 2007). Additionally grapheme-colour synaesthetes often report having vivid spatial number lines, which they report using for adding and subtracting (Sagiv, Simner, Collins, Butterworth, & Ward, 2006). Therefore, it is possible that these synaesthetes were using a quasi-visual form of the inducer, despite the lack of an externally presented one.

As an alternative explanation of the findings from the mathematical Stroop paradigm, Hubbard et al (2006) suggest that the synaesthetes potentially created a spontaneous mental image of the digit as the answer to the sum. Consequently, the VWFA may have been activated by the top-down processes involved in mental imagery. Interestingly, an explanation put forward for studies with the non-synaesthete population showing activation of the VWFA during spoken-word tasks also suggests that this could be due to top-down activation of either orthographic or object-knowledge in visual cortex (Dehaene, Le Clec, Poline, Le Bihan, & Cohen, 2002). Hubbard et al (2006) propose that a mental image of a grapheme could activate the category selective regions of the fusiform gyrus, which has previously been shown to be activated by mental imagery (O'Craven & Kanwisher, 2000). However, to date, this is an aspect of synaesthesia that very little is known about, as objective data to show that a mental image of a grapheme can elicit a synaesthetic concurrent has not yet been provided.

1.5 – Focus of thesis (mental imagery and synaesthesia)

As outlined in the earlier sections, a number of studies have explored the level of visual processing of an inducer required for the generation of a synaesthetic concurrent. Some researchers suggest that the processing of the concept of the inducer is more important than the visual form (Dixon, Smilek, Duffy, Zanna, & Merikle, 2006), and this view has been strengthened by studies which have not involved the external visual presentation of the inducer, but still found evidence of the synaesthetic concurrent being elicited by the mere concept of the inducer (Dixon, Smilek, Cudahy, & Merikle, 2000; Jansari, Spiller, & Redfern, 2006; Smilek, Dixon, Cudahy, & Merikle, 2002a). However, it has been suggested that with this apparently ‘concept-driven synaesthesia’ the concurrent may actually have been elicited by a mental image of the inducer that was spontaneously created by the concept (Hubbard, Manohar, & Ramachandran, 2006). It is therefore important to establish whether a mental image of an inducer can elicit a concurrent. There is some anecdotal evidence that this is the case. For example, the two synaesthetes tested in Ramachandran and Hubbard’s psychophysical study of synaesthesia reported that “if they ‘imaged’ the corresponding Arabic numeral then the corresponding colour was evoked, but more faintly than when looking at the actual numerals” (2001a, p. 979). In contrast, other synaesthetes have reported that imagining a grapheme can evoke a stronger colour than evoked from visually perceiving that grapheme (Ramachandran & Hubbard, 2003a). However, none of these studies have explicitly required the formation of a mental image of a grapheme and used experimental methodology to document the possible subsequent generation of a concurrent. This therefore remains an unanswered question within the synaesthesia literature.

The question of whether a mental image of an inducer can elicit a concurrent can be addressed by considering the two main models of synaesthesia. Although not explicitly discussed in the description of the re-entrant feedback model of synaesthesia, it can be argued that proponents of this theory would predict that a mental image of a concurrent would evoke a concurrent. This theory stresses the importance of top-down processing from the grapheme-concept area of the brain back to the earlier colour processing areas.

Consequently, the external presentation of the inducer would not be a requirement for the concurrent to be evoked, as found with the mathematical Stroop paradigm studies (Smilek, Dixon, Cudahy, & Merikle, 2002a). The important aspect is the concept of the inducer, and as long as a mental image elicited the concept of an inducer, this model would predict that the concurrent would be generated. In their study of concept-driven synaesthesia Smilek et al commented that there are some synaesthetes “who can trigger photisms merely by thinking of, or imagining, the inducing stimulus” (2002a, p. 573), although as outlined already, their interpretation focused on the higher level semantic processes rather than perceptual processes. Similarly, the cross-activation theory can also be used to predict that a mental image of a grapheme would elicit a concurrent. However, as this model stresses the importance of the grapheme-form in the generation of the concurrent, the model would make a more specific prediction; the concurrent could only be elicited, if the top-down processing involved in the mental image generation propagated back to the areas where the grapheme-form is initially processed, which purportedly is the VWFA. This is because this model proposes that the concurrent is a result of cross-activation between the grapheme-form and colour processing areas. Consequently, an exploration of the determinants of the generation of a concurrent from a mental image of an inducer seems a useful method for testing these predictions, and adding to our understanding of the processes involved in grapheme-colour synaesthesia.

It is therefore important to consider what it meant by the terms ‘visual perception’ and ‘mental imagery’. Visual perception can been described as the phenomenon that occurs when an external stimulus is viewed. In contrast, mental imagery can be thought of as a set of internal representations that result in the experience of perceiving an image of a stimulus but without the appropriate external sensory input. Whereas visual perception involves bottom-up mechanisms, which are driven by input from the eyes along with top-down mechanisms, mental imagery can only use top-down mechanisms, and so information within memory underlies these internal events (although mental images are not limited by the exact nature of these memories). Arguably, separation of the concept of a grapheme from a mental image of a grapheme would be a very difficult task, as mental images are formed using top-down processes. Dixon and colleagues (2006; Myles, Dixon, Smilek, & Merikle, 2003) were able to manipulate the concept of externally presented graphemes by using ambiguous grapheme shapes, but forming internally generated images of ambiguous graphemes would require a much more complicated process. Therefore, simply showing that a mental image of a grapheme elicits a concurrent would not provide conclusive support for either model, as the concurrent could be elicited from either the concept or the image of the grapheme. However, the key focus could be the requirement for the visual processing of the grapheme image (as suggested to be a necessity by the cross-activation theory), and whether or not the top-down processing involved in generating the image of the grapheme spread as far back as the early visual areas. This would allow direct testing of the predictions; if, as predicted from the cross-activation theory, the processing of the visual form of the grapheme is essential, then a synaesthetic concurrent would only be elicited when the early visual areas are activated through the generation of the image. In contrast, it can be predicted from the re-entrant feedback model, that as the concept of the inducer should be elicited with all mental imagery processes, a synaesthetic concurrent would be elicited regardless of whether these early visual areas were activated. Accordingly, by exploring the role different imagery processes play in the generation of a synaesthetic concurrent it is possible to directly test predictions made from the two main models of grapheme-colour synaesthesia.

From reviewing the mental imagery literature it is apparent that mental imagery shares many perceptual processes with visual perception. For example, early behavioural studies suggested that mental imagery has similar perceptual qualities to visual perception (Kosslyn, Cave, Provost, & von Gierke, 1988). It has also been proposed that visual perception and mental imagery share many neural substrates. Several neuroimaging studies support this premise; for example, a comparison of whole-brain activation from an image generation task to a comparable perceptual task found that most of the brain areas activated in perception were also activated in imagery (the two conditions activated approximately 92% of the same voxels) (Ganis, Thompson, & Kosslyn, 2004). Furthermore, studies have shown similar content-specific activation in both visual perception and mental imagery. In visual perception studies, specific areas of the brain have been shown to be activated by specific types of objects, such as faces, with the so-called ‘face area’ (fusiform face area or FFA) (Kanwisher, McDermott, & Chun, 1997), and places, with the so-called ‘place area’ (parahippocampal place area of PPA) (Epstein & Kanwisher, 1998). Similarly, these areas are also activated when creating mental images of faces and places. A study comparing FFA and PPA activation in an imagery and perception task, found that although there was greater activation of these areas in the perception task, within individual imagery trials for three of the eight participants it was possible to correctly identify the content of image (i.e.

whether the image generated was of a face or internal/external scene) by looking at fMRI data (O'Craven & Kanwisher, 2000). The authors argued that these similar activations most likely reflect a perceptual representation of the stimulus within the mental image, as the same region was found to be selectively activated in both imagery and perception. Additionally a study comparing activation when seeing or visualising faces, chairs and houses, found content-dependent activation during the imagery condition in small subsets of regions that had shown category-related activation when visually presented with the same stimuli (Ishai, Ungerleider, & Haxby, 2000). Importantly therefore, there is support for the idea that imagery and perception share many specific specialised functions.

Some research even suggests that under certain circumstances, for some individuals, a mental image can be shown to activate retinotopically organised primary visual cortex (see Kosslyn & Thompson, 2003 for a review). Primary visual cortex (also referred to as V1, Brodmann's area 17, or striate cortex), located in the occipital cortex, is the first visually responsive cortical area, and receives information directly from the retina, through the LGN. Researchers within the field of mental imagery have paid particular attention to whether this area is activated during mental imagery due to the way it is retinotopically organised (Kosslyn, 2008). Cells within primary visual cortex mostly respond to stimulus orientation, and the cells have been found to be distributed throughout the cortex so that the pattern of activation forms a topographic map of the visual field (Heeger, 1999). The centre of the cortical area thus responds to the centre of the visual field, although the mapping is distorted so that more of the cortical surface responds to the central area of the visual field (Sereno et al., 1995).

Despite this, the relative size of an object in the visual field is seemingly still represented, so that a large object will activate a larger area of cortical cells (Fox et al., 1986). Neuroimaging studies have found activation of this area during mental imagery tasks (Klein et al., 2004; Slotnick, Thompson, & Kosslyn, 2005), and consequently it has been proposed that this activation supports the idea that it is possible for mental images to be 'percept-like' in quality. In what is referred to as the "Reality Simulation Principle" (Kosslyn, 2008), and also "Perceptual Anticipation Theory" (Kosslyn, 1994), it has been proposed that a function of such percept-like mental imagery is the generation of internal representations that mimic corresponding events or objects in the world. According to this theory images "arise when one anticipates perceiving an object or scene so strongly that a depictive representation of the stimulus is created in early visual cortex" (Kosslyn & Thompson, 2003, p. 724). In other words imagery can be seen as a form of hyper-priming, in which the top-down processes involved in perception, send 'messages' along the connections that run back from the areas in the temporal lobe to the retinotopically organised areas of primary visual cortex (referred to as the 'visual buffer').

Activation of this area is potentially of particular importance to the current thesis. In particular, the Perceptual Anticipation Theory (Kosslyn, 1994) can be used to suggest that when a synaesthete generates a percept-like image of a grapheme, this would activate the same neural mechanisms as activated if they anticipated actually seeing that grapheme. This 'anticipation' of viewing the grapheme would potentially create a depictive representation of the grapheme in the retinotopically organised 'visual buffer', that is similar to the representation that would be activated in these areas if the grapheme were actually perceived. If the image was then processed in the same way as an externally presented visual percept of a grapheme would be, it could be predicted that this image of an inducer would result in a synaesthetic concurrent. In order to provide support for the cross-activation theory, and argue that a synaesthetic concurrent elicited by a mental image of a grapheme shows the importance of visual processing in synaesthesia, the actual mental image of the grapheme therefore needs to have percept-like qualities in order for the grapheme-form to be processed in the early visual areas. However, if the mental image results from activity only in the 'higher-order' or association areas then a synaesthetic concurrent elicited from that mental image would not occur as a result of visual processing (as suggested by the re-entrant feedback model).

Importantly, a distinction has been made within the imagery literature concerning different imagery processes, as not all imagery processes are thought to activate these early visual areas in the primary visual cortex. It has been suggested that mental imagery makes use of the same two processing pathways as visual perception (Kosslyn, 2008); the ventral ('what') and dorsal ('where') streams (Ungerleider & Mishkin, 1982). For example, patients with damage to areas in the ventral pathway (going from the occipital lobe down to the inferior temporal lobe) or dorsal pathway (going from the occipital lobe up to the posterior parietal lobe) have been found to have differing deficits in mental imagery processes (Farah, Hammond, Levine, & Calvanio, 1988; Levine, Warach, & Farah, 1985; Luzzatti, Vecchi, Agazzi, Cesa-Bianchi, & Vergani, 1998). This has been used to suggest that there are distinct 'object imagery processes' (including details such as object form and colour) and 'spatial imagery processes' (including details such as location and position), which potentially have differing underlying neural mechanisms. Furthermore, neuroimaging studies provide support for the idea that these purportedly distinct imagery processes make use of different neural pathways; whereas generating a detailed image of an object can activate the early visual areas (Klein, Paradis, Poline, Kosslyn, & Le Bihan, 2000; Kosslyn et al., 1999; Kosslyn & Thompson, 2003; Sparing et al., 2002), a spatial imagery process such as mental rotation of images activates areas within the parietal cortex (Alivisatos & Petrides, 1997; M. S. Cohen et al., 1996; Harris & Miniussi, 2003; Jordan, Heinze, Lutz, Kanowski, & Jancke, 2001). Accordingly, a general consensus has been developed within the imagery literature that there are two broad types of imagery processes; those using object processes and those using spatial processes (Mellet, Petit, Mazoyer, Denis, & Tzourio, 1998).

The idea that there are distinct imagery processes that utilise the object pathways and those that draw on spatial pathways is therefore important to consider for the current thesis, as the role that these processes may play could have important implications for the currently proposed models of synaesthesia. For example, the re-entrant model (Smilek, Dixon, Cudahy, & Merikle, 2001) predicts that as long as the mental image of the inducer elicited the concept of the grapheme, the concurrent would be generated; consequently, the specific type of imagery process would not be expected to play a role, as activation of the early visual areas would not be a necessity in the generation of the concurrent. Therefore, the re-entrant model predicts that a concurrent could be elicited from both object and spatial imagery processes. However, in sharp contrast to this, the cross-activation theory (Ramachandran & Hubbard, 2001a) predicts that the type of imagery process would have an effect on the subsequent likelihood of the generation of the synaesthetic concurrent. Tasks that require object imagery processes, especially those that are thought to activate the early visual areas, would arguably be likely to generate a concurrent according to the cross-activation model, as the mental image of the grapheme would be processed in a very similar way to a visual percept of that grapheme. Conversely, the cross-activation theory would predict that a task requiring spatial imagery processes would be unlikely to generate a synaesthetic concurrent, as the spatial processes would not require a visual representation of the grapheme. Therefore, at a neuroanatomical level, spatial imagery processes would not be expected to activate the early visual form areas that the cross-activation theory proposes to be necessary for the generation of a synaesthetic concurrent.

Outline of thesis

In conclusion, the focus of this thesis is the possibility of generating a synaesthetic concurrent from an internally generated mental image of a grapheme. Previous research has documented the generation of the concurrent, which has been shown to have perceptual qualities very similar to ‘real’ colour, from externally presented visual representations of a grapheme. Research has also suggested that it is possible to evoke a concurrent without the external presentation of the inducer, but with an internally generated concept. However, to date, the question of whether a mental image of an inducer can elicit a concurrent has only been answered with synaesthetes’ subjective reports. Consequently, this is an aspect of grapheme-colour synaesthesia that merits exploration, in order to further our understanding of the phenomenon. As there is a great deal of research that suggests mental images not only share perceptual qualities with visual percepts, but that mental imagery shares many neural pathways with visual perception, it can be hypothesised that "synaesthesia can occur with incomplete activation of the entire cascade of sensory signalling normally propagated during perception" (Grossenbacher & Lovelace, 2001, p. 38).

Importantly however, there are purportedly distinct imagery processes; like visual perception, mental imagery is thought to use both the ventral pathway (for object imagery) and the dorsal pathway (for spatial imagery processes). Specifically therefore, this thesis will explore the role that these purportedly distinct imagery processes might play as determinants of the concurrent. This is because, by exploring the issue of eliciting a concurrent from different imagery processes, it is possible to directly test predictions based on the two main models of grapheme-colour synaesthesia: the cross-activation theory and the re-entrant feedback model. These models differ on the level of representation of the grapheme from which the concurrent is proposed to be elicited. While the re-entrant feedback model suggests that the concept of the inducer feeds back to the early colour processing area to elicit the concurrent, the cross-activation theory posits that the concurrent is evoked through direct cross-activation between the grapheme-form processing area and colour processing area early in the visual stream. The re-entrant feedback model can therefore be used to predict that a mental image of a grapheme would evoke a concurrent, as the important element is the concept. In contrast, the cross-activation theory can be used to predict that the image of the inducer will elicit the concurrent, but only if the imagery processes engage the early grapheme-form processing areas. The current thesis can therefore directly test these predictions, by exploring the generation of a concurrent from a mental image of a grapheme utilising object imagery processes (Experiment 1), and the generation of a concurrent from a mental image of a grapheme utilising spatial imagery processes (Experiment 2). The findings of these experiments have then been further explored with Experiments 3, 4 and 5, to more systematically explore the generation of a concurrent from an internally generated mental image of an inducer.

Chapter 2 – Generating a synaesthetic concurrent from a mental image of a grapheme: the role of object imagery processes (Experiment 1)

2.1 – Experiment 1 Introduction

Experiment 1 is an initial exploration of the generation of a synaesthetic concurrent from a mental image of a grapheme. As outlined in Chapter 1, to date there is only anecdotal evidence to suggest that imaging an inducer elicits a concurrent (Ramachandran & Hubbard, 2001a, 2003a). The two main models of grapheme-colour synaesthesia can be used to make predictions about likely consequences of a synaesthete creating a mental image of an inducer, and in general, both models would predict that the concurrent would be evoked. Importantly however, the explanations that can be given as to why the concurrent would be elicited differ between the models, due to the representational level each model suggests that the concurrent is elicited by the inducer. The re-entrant feedback model can be used to predict that a mental image would elicit the concurrent, because the mental image could activate the concept of that grapheme; according to this theory it is the concept of the grapheme that evokes the concurrent. In contrast, the cross-activation model can be used to predict that a mental image would elicit the concurrent, so long as the processes engaged in the image generation involved processing the visual form of the grapheme. Experiment 1 therefore aimed to explore whether a synaesthetic concurrent could be elicited from a mental image of a grapheme, with a specific focus on object imagery processes that are thought to involve the visual processing of the grapheme-form.

Object imagery processes

Object imagery is thought to involve details of an object's shape, and shape-related properties such as colour (Kosslyn, 2008) and as outlined in Chapter 1, the processes involved in the generation of object imagery are thought to utilise the ventral visual pathway. Potentially therefore, an image of a grapheme generated with object imagery processes could have percept-like qualities, and the top-down object-imagery processes involved could propagate back to the early visual areas. When considering the question of whether a mental image could have percept-like qualities, it is important to note that there has been a long-standing debate within the imagery literature concerning the format of mental images (see Tye, 1991). For example, it has been argued that mental images cannot be picture-like, but rather they can only be descriptive in nature, and represented in a language–like system (Pylyshyn, 2002). In contrast, others have argued that mental images are not limited to descriptions, and proponents of this account suggest that mental images can have a similar representational format to visual percepts (Kosslyn, 1994, 2005). Accordingly, the theory states that mental images can depict the object within the image. The term 'depict' refers to the idea that each part of the representation corresponds with specific parts of that object, so that the distances between these parts in the representation of the object reflect the distances between these parts on the actual object (Kosslyn, 2005). Crucially, proponents of this theory therefore suggest that inspecting a mental image of an object, such as a grapheme, could be similar to visually perceiving that object. This implies that it would be possible for a mental image of a grapheme to have depictive qualities.

Of interest to the current study is a recent study that explored the format of mental images, and specifically whether mental images of letters can be depictive in nature (Thompson, Kosslyn, Hoffman, & van der Kooli, 2008). The study assessed whether it was possible to inspect ‘implicit’ properties within a mental image, as one can with a visual percept. The term ‘implicit’ referred to aspects of an object that were not immediately available within an internal representation of that object. For example, when visually presented with an uppercase ‘A’ the presence of the horizontal line, and two diagonal lines may be noticed immediately, whereas the presence of an enclosed shape may not be immediately accessible, and so this triangle would be an ‘implicit’ property that was only noticed when it was the focus of attention. Accordingly, within a visual percept the presence of an implicit property would take longer to detect than an explicit property. Thompson et al (2008) proposed that if mental images use the same representational format as visual percepts then, relative to explicit properties, implicit properties of an object should be equally difficult to inspect in a mental image as they are in a visual percept. However, if mental images use language based descriptions, as suggested by Pylyshyn (2002) the implicit properties would be more difficult to detect in imagery than perception. According to this view, although the previously stored explicit properties would be accessible from a language based description, it would not be possible to ‘inspect’ the visual representation to ‘see’ the implicit ones. After conducting an initial study to identify the explicit and implicit properties of graphemes, Thompson et al (2008) found that participants were able to accurately detect both explicit and implicit properties of a grapheme within a mental image, and importantly, the difference in response latency for the two property types within the imagery condition was similar to that found with the visual perception condition. The authors suggested therefore that they had found strong support for the idea that mental images of letters can use depictive representations, and for the idea that mental images share a similar format as visual percepts.

Further support for the view that mental images can have percept-like qualities can be found with the body of research which suggests that imagery engages similar brain mechanisms as those used in visual perception, indicating that a visual image of a grapheme could initiate the same sequence of processing as that produced by the visual presentation of a grapheme. For example, an early PET study assessed whether mental images of graphemes would activate early visual areas, including retinotopically organised primary visual cortex (Kosslyn et al., 1993). Kosslyn et al aimed to see whether the size of the mental image formed was related to the size of activation found in the retinotopically organised areas of visual cortex, as has been shown with visual perception (Fox et al., 1986). To this end, participants were instructed to form mental images of letters that were either as small or as large as they could visualise, so that the entire letter was still visible within the image. To ensure a mental image was formed, participants subsequently made a forced-choice characteristic-judgement about the letter (for example, does the letter have any straight lines). The PET results suggested that the size of the mental image was indeed related to the activation found, with the smaller images activating a posterior portion of the visual cortex, while the larger letters additionally activated an anterior region, suggesting that the larger images spread into more peripheral parts of the representation in the visual field. This study therefore provides support for the idea that mental images of graphemes can activate early visual areas, and significantly, the pattern of activation reflects the pattern that would be found with a visually perceived grapheme. Furthermore, these findings have since been re-analysed to explore whether the amount of blood flow measured by PET in these areas was related to the time taken to complete the ‘grapheme characteristic’ judgement task (Kosslyn, Thompson, Kim, Rauch, & Alpert, 1996). The idea was that if primary visual cortex activation played a functional role in image generation then the amount of activity in that area should be related to the ‘quality’ or vividness of the mental image (i.e. a better quality image should result in a faster response time in the imagery task). Importantly, the re-analysis found that the time taken to evaluate the mental image of each letter was negatively correlated with rCBF in primary visual cortex; the slower times suggested that poorer quality images were associated with less activity in the area of interest. The authors therefore argued that the amount of activation was systematically related to the quality or vividness of the image being visualised, in addition to its spatial properties as indicated by their earlier study.

Therefore, evidence suggests that mental imagery uses some of the same neural mechanisms as visual perception, sharing low-level anatomical substrates, and importantly these areas play a functional role in imagery, as well as perception. Consequently, it could be predicted that internally creating a mental image of a grapheme would result in similar neural processes as when perceiving an externally presented grapheme. However, it is important to note that not all studies exploring the neural processing involved with mental images of graphemes have come to the same conclusion. For example, Raij (1999) used magnetoencephalography (MEG) to identify the location and temporal sequence of neural activation when participants created mental images of letters (as prompted by an auditory cue) and made a visuospatial judgement about the properties of the image. Comparing activation in the imagery task to activation found with audiovisual stimuli presentation showed that, although the imagery task activated a subsection of the neural network activated by the audiovisual stimuli, activation of early visual areas was only found in one of the ten participants. Similarly, a PET study comparing rCBF when visualising letters and text to internally listing the letters / text found no significant activation of the primary visual cortical areas (Gulyas, 2001).

One potential explanation for this difference in findings relating to the activation of early visual areas comes from a meta-analysis of studies exploring the activation of primary visual cortex with mental imagery (Kosslyn & Thompson, 2003). This review found that from the neuroimaging studies of mental imagery published between 1987 and 2002, 17 reported significant activation of primary visual cortex and 23 did not. Kosslyn and Thompson proposed three factors to explain these potentially conflicting findings; i) the sensitivity of the neuroimaging technique, ii) the requirement for the participant to inspect high resolution details within the image, and iii) the requirement for the participants to form an image of a shape rather than a spatial pattern. Therefore, as noted by Raij (1999), the lack of activation of primary visual cortex found with imagery task used could be due to the limited spatial resolution of MEG, or because the task used did not require the inspection of high resolution details within the image. The task used by Raij involved identifying letters as either ‘ascenders’ (e.g. ‘d’, ‘h’, ‘k’, ‘t’) or ‘descenders’ (e.g. ‘g’, ‘j’, ‘p’, ‘q’, ‘y’) and therefore did not require an image with a high level of resolution. Similarly, in the imagery conditions of the Gulyas study (2001), participants were asked to visualise each letter of the Hungarian alphabet. For each letter image participants were instructed to ‘carefully inspect the straight and curved lines in each letter” (Gulyas, 2001, p. 320), but there was no behavioural measurement taken of the level of detail in the images. As a result, the lack of activation in early visual areas could again be due to the task requirements, as the task did not require a high level of image resolution.

Therefore, the imagery task to be used in Experiment 1 needs to not only involve the generation of a mental image of the grapheme shape, it also needs to involve a judgement that requires inspection of high-resolution details. Kosslyn and Thompson (2003) specifically state that it was not the need to simply use high level resolution when creating images, as this was not found to be a predicting factor in their review. Instead, the requirement to make note of, or to inspect a high resolution detail was important. Selection of an imagery task with such a requirement will therefore add support to the claim that the early visual areas were involved in the imagery processes required for successful task completion. Consequently, there will be support for the idea that any concurrent evoked may have been elicited from the visual processing of the grapheme form. The premise would be that if the mental image of the grapheme is able to *stimulate* the primary visual cortex it will then be processed by subsequent visual areas as a whole, as if it were a visual percept. This would allow the subsequent activation of grapheme recognition areas and the cross-activation/dis-inhibition processes to induce the synaesthetic concurrent, supporting Grossenbacher and Lovelace’s suggestion (2001) that synaesthesia can occur without the normal progression of sensory signalling found in visual perception of a grapheme.

Task requirements to measure synaesthetic concurrent

The objective measurement of a potential synaesthetic concurrent from the mental image is also important to consider for the current study. Many studies exploring synaesthesia from externally presented graphemes have used a colour conflict paradigm to measure the occurrence of a synaesthetic concurrent (as discussed in Chapter 1). Typically these tasks involve some form of colour manipulation, whereby graphemes are visually presented either in a colour that matches the concurrent evoked by that grapheme (the congruent condition), or in a colour not evoked by that grapheme (the incongruent condition). The subsequent ‘congruency effect’ (the difference in the dependent variable observed as a result of the colour manipulation) is taken as an objective measurement of the synaesthetic concurrent. For example, in the modified Stroop task participants were asked to name the visual colour of stimuli, and for synaesthetes a difference in reaction time was found for the two colour conditions (congruent or incongruent) whereas for matched controls the colour did not impact reaction time (Mills, Boteler, & Oliver, 1999; Odgaard, Flowers, & Bradman, 1999; Wollen & Ruggiero, 1983). The difference in response times between the two colour conditions is thought to be due to the conflict between the ‘real’ colour and the colour of the concurrent. The colour conflict paradigm has also been used to explore synaesthetes’ cognitive abilities such as memory. For example, a single-case study found that a synaesthete’s ability to accurately recall digit-matrices was impaired when the digits were presented in incongruent colours, relative to the congruent condition (Smilek, Dixon, Cudahy, & Merikle, 2002b). Additionally, studies have shown the physiological effect of perceiving congruently and incongruently coloured inducers. When visually presented with incongruently coloured inducers, synaesthetes have been shown to have a physiological reaction, such as pupil dilation, which is controlled by the autonomic nervous system (Paulsen & Laeng, 2006). A recent study also suggested an emotional reaction to viewing incongruently coloured inducers (Callejas, Acosta, & Lupianez, 2007). Furthermore, neuroimaging evidence suggests that being visually presented with an incongruent grapheme is associated with activation in areas of the brain associated with cognitive control mechanisms (Weiss, Zilles, & Fink, 2005). Overall, it appears that the colour conflict paradigm is a well-established method for measuring the synaesthetic concurrent, by looking at the effect the conflict has on task performance.

Importantly though, in order to explore mental imagery and synaesthesia it is not possible to manipulate the colour of the stimuli “viewed”. However, it is possible to adapt the congruency effect, as shown by a study that was conducted to explore the influence of synaesthetic colours on visual perception (Smilek, Dixon, Cudahy, & Merikle, 2001). Participants’ task was to find and identify black targets digits presented on backgrounds that were either congruently or incongruently coloured with the target for that trial. When the background was congruent with the synaesthetic colour experienced from the target digit it was more difficult for the synaesthete to locate and identify the target, than when the background was incongruent. The authors concluded that the synaesthetic colours had influenced the visual perception of the black digits, relative to the background. This paradigm could therefore be adapted for use with a mental imagery task, to see whether changing the background colour that a grapheme is visualised against will influence perception of mental images of graphemes. If a synaesthete’s ability to generate and inspect a mental image of a grapheme against a congruently coloured background is found to differ from when the background is incongruently coloured, support would be provided for the idea that a mental image of a grapheme can elicit a synaesthetic concurrent.

Aims and hypothesis of Experiment 1

In summary, Experiment 1 has combined an experimental task from the synaesthesia literature with one from the mental imagery literature to test the hypothesis that a synaesthetic concurrent can be elicited from a mental image of an inducer. In order to be confident that participants were forming mental images of the graphemes using object imagery processes, a behavioural task was chosen that required participants to form a mental image of an upper case letter and to then make a size based decision about the letter (see Figure 2.1). A similar version of this task has been used within the mental imagery literature (Ganis, Thompson, & Kosslyn, 2004; Kosslyn et al., 2004; Mast, Ganis, Christie, & Kosslyn, 2003; Mast & Kosslyn, 2002). In each trial participants formed a previously learnt mental image of a grapheme within an empty circle that was visually presented on a computer screen. Subsequently, the circle was divided into three equal sections, and the task was to decide which of two indicated sections more of the visualised grapheme would fall in. It has been suggested (Ganis, Thompson, & Kosslyn, 2004) that this task requires the generation and inspection of a high resolution mental image, as in order to make the correct forced-choice decision the mental image needs to have a high level of detail. This requirement for high resolution purportedly increases the chance of activation of the early visual areas, and so importantly for the current study, allows the focus to be on object imagery processes that potentially involve the visual processing of the grapheme form.

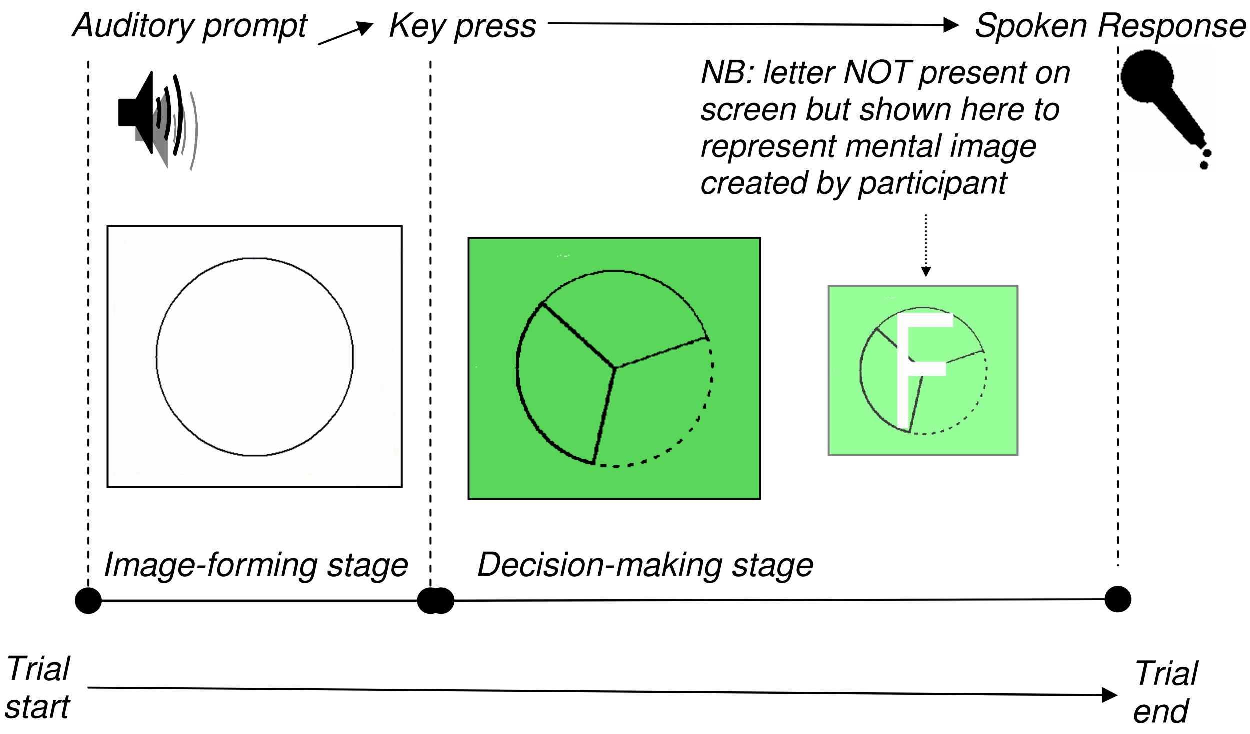


Fig 2.1: Example display of the Image-Forming Stage and Decision-Making Stage in the trial procedure of Experiment 1

The occurrence of a synaesthetic concurrent was measured by comparing performance on the mental imagery task under different colour conditions; during the decision-making stage of each trial the background colour was manipulated so that it was congruent or incongruent with the concurrent associated with the grapheme being visualised. In addition there was a 'no colour' condition, in which the screen remained achromatic as it had been in the image-formation stage. For synaesthetes it was hypothesised that background colour would affect performance in the mental imagery task, resulting in a significant difference in response times between the two colour conditions.

However, for non-synaesthetic matched controls it was hypothesised that no difference in performance across conditions would be found. Based on the findings of Smilek et al (2001) it was predicted that synaesthetes would be slower to perform the imagery task in the congruent condition, as the synaesthetic concurrent would make it more difficult to separate the image of the grapheme from the background when the two colours matched.

2.2 – Experiment 1 Method

Participants

All participants were over 18 years of age, in good mental health and had normal or corrected-to-normal visual acuity according to self-report, and gave written informed consent prior to participating.

Synaesthetes: Six grapheme-colour synaesthetes participated in Experiment 1, four female and two male. For each synaesthete assessments were made of the 'genuineness' of their reported synaesthesia and also the phenomenological experience of their synaesthetic concurrents. With regards to the genuineness, a modified version of the Test of Genuineness (ToG) (Baron-Cohen, Wyke, & Binnie, 1987) was completed in order to compare the similarity of each synaesthete's colour responses to given stimuli over two points in time. Whereas the original ToG used a series of words and non-words in addition to graphemes, this modified version assessed only the internal reliability of their synaesthetic colour responses to each letter of the alphabet and digits 0-9. The synaesthetes were not told that there would be a re-test session, and for this study the test and re-test stages were between 6-12 months apart. As shown in Table 2.1, the similarity of responses for each synaesthete ranged from 92% to 100%, with a mean of 97% (standard deviation (SD) = 3.7).

With regards to the phenomenological experience of the synaesthetic concurrent, two aspects were explored. First, the synaesthetes were asked to indicate the spatial location of the concurrent: whether when seeing an externally presented grapheme, they experience their synaesthetic colour as if it were “out there on the page or in external space” or “in your mind’s eye or in your head”. This was because it has previously been suggested that there can be a behavioural difference between synaesthetes who report experiencing the synaesthetic concurrent in ‘external space’ (who are referred to as ‘projectors’), and ‘internal space’ (who are referred to as ‘associators’) (Dixon, Smilek, & Merikle, 2004; Ward, Li, Salih, & Sagiv, 2006). This resulted in four of the synaesthetes being classified as associators, and two as projectors. Second, in order to explore the synaesthetes’ subjective experience of a concurrent from an internally generated mental image of a grapheme, they were asked to report whether there was a qualitative difference between the concurrent elicited from an externally presented written grapheme to the concurrent elicited from a mental image of a grapheme. This was because there are conflicting anecdotal reports in the literature concerning differences in these experiences (Ramachandran & Hubbard, 2001a, 2003a), and so this was a potential variable that could affect the results of the study. The synaesthetes were asked to indicate which form the more vivid concurrent was elicited from, or whether there was no difference. The ‘imagined’ form was indicated as eliciting a more vivid concurrent for three of the synaesthetes, while the ‘written’ form was more vivid for two synaesthetes, and one reported that there was no difference. This question was asked after completion of the experimental phase of the current study.

Non-synaesthete matched controls: For each synaesthete, ten gender and age matched controls were recruited. After completing the experimental phase of the study the controls were asked if they experienced any synaesthetic-like experiences (i.e. did they associate particular colours with words, numbers, days of the week, months of the year) and when a positive response was given their data was withdrawn. This happened for one control matched for synaesthete KD, resulting in a total of 59 controls being used for the current study.

Comparison of synaesthetes to matched controls: Table 2.1 summarises the characteristics of the synaesthetes and their matched controls. The mean age of the synaesthetes (32.8, S.D = 12) and the mean age of the controls (33.2, S.D. = 11.1) did not differ significantly (t(63) = 0.08, p > .05, *d* = 0.03). In order to compare reported vividness of imagery all participants completed the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973). This subjective self-report measure asks participants to create a mental image of a series of four pictures, and to then focus on four different aspects of the image and rate how “clear and vivid” these are, on a scale of 1-5 (1=perfectly clear and as vivid as normal vision, 5=no image at all). Participants completed it once with eyes open and again with eyes closed, resulting in possible scores between 32 and 160, with a lower score indicating more vivid imagery. A recent comparison of synaesthetes and non-synaesthetes’ reported imagery vividness found that as a group the synaesthetes reported significantly more vivid imagery than their non-synaesthete matched controls using the VVIQ (Barnett & Newell, 2008). Although the current data shows that same pattern, with the synaesthetes (mean = 72, S.D = 13.9) reporting slightly more vivid imagery than controls (mean 81, S.D = 26.2), importantly for the current study this difference was not significant (t(63) = 0.8, p >.05, *d* = 0.45). Additionally, only one synaesthete (SR) had a score that fell more than one standard deviation away from the control group mean score.

Table 2.1: Participant demographics for synaesthetes and each synaesthete's corresponding group of matched controls in Experiment 1, including each synaesthete's modified Test of Genuineness (Baron-Cohen, Wyke, & Binnie, 1987) test-retest reliability percentage (ToG %), location of colour experience ('projector' or 'associator'), comparison of colour vividness from written/imagined graphemes, and each synaesthetes' actual and control groups' mean score on the Vividness of Visual Imagery Quota (VVIQ; Marks, 1973)

Synaesthetes							**Matched Control Group**	
ID	*Gender*	*Age*	*ToG %*	*Colour location*	*More vivid experience from written/ imagined graphemes*	*VVIQ Total*	*Age Mean (SD)*	*VVIQ Mean Total (SD)*
KD	male	40	94	associator	imagined	66	42.0 (2.9)	94 (28)
DS	male	29	94	associator	written	76	28.8 (4.3)	79 (25)
RW	female	50	100	associator	imagined	81	49.8 (4.5)	72 (29)
VE	female	23	100	projector	written	88	21.1 (2.8)	81 (30)
ZV	female	18	100	projector	same	73	22.4 (3.2)	77 (22)
SR	female	39	92	associator	imagined	48	36.3 (5.5)	83 (24)

Materials

The materials for Experiment 1 were designed for each synaesthete with regards to the graphemes and background colours used. This was based on a pre-study assessment, in which each synaesthete provided ratings for each letter of the alphabet, on a scale of 1-10, for the strength of their synaesthetic concurrent elicited (where 10 was the strongest). Additionally they supplied a visual representation of their synaesthetic concurrent for each grapheme, so that the colours used in the experiment proper were as close as possible to the specific colours each individual experienced. Synaesthetes did this by selecting the most suitable colour for each grapheme using the colour palette within the ‘font’ tab in Microsoft Word, which provided RGB values that could be used within other software formats.

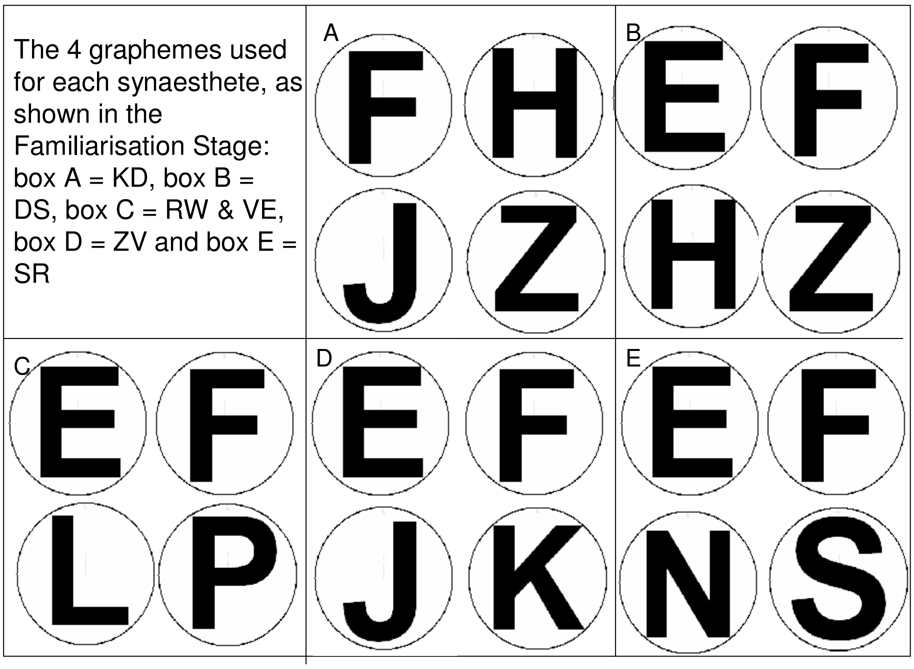
For the experiment proper, four graphemes for each synaesthete were chosen using three criteria to ensure that i) for each synaesthete the synaesthetic colours experienced were equally vivid or strong, ii) that the colour experienced was appropriate for the testing procedure, and iii) that the graphemes were of similar difficulty in the image forming and inspection stages of the task. With regards to the synaesthetic colour vividness, the subjective rating of the strength of colour experience for each grapheme was assessed in the pre-study assessment; this is because synaesthetes have reported that not all graphemes result in the same subjective strength of a synaesthetic concurrent. Graphemes were only used in the current study if the rating was in the top 10% of that individual synaesthete’s ratings (using a rating scale of 1-10, where 10 is the strongest). With regards to the appropriateness of synaesthetic colour, the colour experienced for each of the four graphemes had to be suitable for the testing procedure. This meant that the colour was visible on a computer screen (e.g. not too close to white and not too dark), and that the colours of the 4 chosen graphemes were visually distinguishable from each other. Finally, the difficulty of image formation and inspection was also considered, as the four graphemes chosen for each synaesthete to visualise throughout the study needed to require equally difficult size-based decisions. For each grapheme, the three different orientations of the divided circle chosen for the experiment proper were selected using the Kosslyn procedure (Mast, Ganis, Christie, & Kosslyn, 2003; Mast & Kosslyn, 2002). Prior to the main study a group of non-synaesthetic participants (n=10) were presented with a series of graphemes (all asymmetrical on the vertical axis) within an outline of a circle on a computer screen. The circles were divided into three equal sections, and there were ten possible orientations of this divided circle (each n+36^0 clockwise from upright). One section of the circle had a thick line round it, and one had a dashed line. Participants had to indicate (with a key press) as quickly as they could whether more of each grapheme fell into the section of the circle with the dashed or thick line around it. The graphemes were chosen for use in the main study if they had a minimum of three possible tridents of different angles of rotation with an accuracy rate of between 60-80% (to avoid floor and ceiling effects).

When possible, if more than four graphemes were found to be suitable for an individual synaesthete, then the graphemes chosen were the same from synaesthete to synaesthete to increase similarity in testing. However, this was not possible for all graphemes for all synaesthetes and so this has some implications for any comparison of error rates and response times from synaesthete to synaesthete as difficulty levels were not exactly the same. In addition to the visual stimuli, sound files were created for the auditory prompts, which had a female voice saying the grapheme name to be visualised.

The study was run on a PC using the software E-Prime. A different E-Prime script was developed for each synaesthete based on information derived from the pre-study assessment. The scripts differed only in the selection of colours for the backgrounds used in the decision making stage of each trial, and the stimuli used (i.e. the four graphemes to be visualised). In the congruent condition the background colour matched the colours provided by the synaesthetes for each of the graphemes, from the pre-test assessment. In the incongruent condition the background colour was one of each of the colours from the other three graphemes used in this study. A 1:3:1 ratio of congruent, incongruent and ‘no colour’ trials was used.

Procedure

Main study: Participants were given both written instructions on the computer and spoken instructions about the main task in the study (see Appendix A). They wore headphones, held a microphone in their hand, and were seated in front of a computer screen. The first stage was a familiarisation stage in which participants were asked to practice forming images of the four graphemes to be used in the upcoming trials (see Figure 2.2).



The 4 graphemes used for each synaesthete, as shown in the Familiarisation Stage: box A = KD, box B = DS, box C = RW & VE, box D = ZV and box E = SR

Fig 2.2: Visual displays of the four graphemes each synaesthete (and matched control group) was presented with in the Familiarisation Stage of Experiment 1.

The experiment proper then began, which started with 12 practice trials. In each trial there were two stages (see Figure 2.1). At the start of the *image-forming stage* participants heard the name of the letter via the headphones at the same time as a black outline of a circle appeared in the centre of a white screen. The participants' task was to create an upper-case mental image of the prompted grapheme within the circle, as similar as possible to those seen in the familiarisation stage. Once the participant had made this image as clear and vivid as they could, they pressed the spacebar which activated the start of the *decision-making stage*. The circle then appeared divided into three equal sections, which varied in orientation from trial to trial. Two of the three sections were highlighted, one with a thicker line, and another with a dashed line. The task for each trial was to decide whether more of the grapheme in their mental image would fall into the section of the circle with the thick line around it or the section with the dashed line. Their response was spoken, saying either “thick” or “dashed”, and they were asked to respond as quickly as possible without sacrificing accuracy. The time from pressing the spacebar to saying the response was recorded as the decision time, and the choice of response was noted by the experimenter. During the *image-formation stage* the background remained white, for all trials. The background colour of the screen during the *decision-making stage* changed from trial to trial, so that it matched the colour of the synaesthetic concurrent associated with the grapheme being visualised (congruent), did not match (incongruent) or it remained white (‘no colour’).

In total, 120 trials were presented in a random order. Each of the four graphemes was used with the divided circle positioned in three different orientations, so that the thick and dashed sections were never in the same place for the same grapheme, within the same condition. Overall, 50% of the correct answers were ‘dashed’, and the other 50% were ‘thick’, with the correct answer having been predetermined using the data from the pilot testing with non-synaesthetes, as described earlier.

2.3 – Experiment 1 Results

Comparison of groups: To explore the effect of colour on task performance, the mean response time (RT) in the *decision-making stage* for each participant in each condition was calculated for correct responses. Trials identified as outliers (using stem and leaf procedures from SPSS package 10.1) were removed independently for all conditions, for each participant. Outliers were trials with a response time which fell more than 1.5 times the interquartile range above the third quartile, or below the first quartile (computed from Tukey's hinges). This procedure resulted in the removal of between 3% and 8% (mean = 5.2%) of trials per synaesthete, and between 0% and 13% (mean = 4.6%) of trials per control participant. Table 2.2 shows the mean RTs for the synaesthetes (n=6) and controls (n=59). A repeated-measures ANOVA with 'colour condition' (congruent, incongruent, and no colour) as a within-group factor, and 'group' (synaesthete and non-synaesthete) as a between-group factor found a significant effect of group ($F(1,63) = 4.93$, $p = .03$, $\eta^2 = .07$), no significant effect of colour ($F(2,63) = 0.14$, $p = .87$, $\eta^2 = .002$), and no interaction between these factors ($F(2,63) = 0.03$, $p = .97$, $\eta^2 = .001$). As can be seen in Table 2.2, the synaesthetes were faster than the controls across all conditions, but within groups there was little difference between conditions. As a group the 'congruency effect' (CE, the mean difference between the congruent and incongruent trials) for the synaesthetes (37.3, S.D = 283.2) was only slightly larger than the CE found with the controls (30.9, S.D = 314.6). The mean error rates (ER) were also very similar for the two groups, with the controls (17.7% S.D = 12.8) having a slightly larger ER than the synaesthetes (12.8% S.D = 10.6), and this difference was not found to be statistically reliable.

Table 2.2: Mean response times (RTs in ms) for synaesthetes and controls in Experiment 1 as a function of colour condition (congruent, incongruent and 'no colour') with standard deviations (SD) in parentheses.

Group	**Mean RT (ms) and SD in colour condition**		
	Congruent	*Incongruent*	*'No Colour'*
Synaesthetes	1447 (237)	1410 (249)	1449 (272)
Controls	2313 (1012)	2282 (938)	2290 (919)

Comparison of each synaesthete to their matched control group: To examine the effect of colour in more detail, the performance of each synaesthete was compared to the performance of their individual matched control group. This approach has been used in previous studies that have shown that the lack of a reliable group effect can be due to important individual differences found within the synaesthete population (Hubbard, Arman, Ramachandran, & Boynton, 2005). Mean RTs for trials with correct responses within each condition were calculated for each synaesthete and for their corresponding group of matched controls, as shown in Table 2.3.

Table 2.3: Mean response times (RTs) as a function of colour condition (congruent, incongruent and no colour), and Error Rates (ERs) for synaesthetes and each synaesthete's corresponding group of matched controls in Experiment 1 (standard deviations in parentheses for RTs and ERs).

	Mean RT (ms) and SD in colour condition			***Mean % Error Rate***
	Congruent	*Incongruent*	*'No Colour'*	
KD	1063 (194)	1031 (235)	1035 (213)	8.3
KD controls	2182 (939)	2171 (864)	2284 (992)	18.7 (10.2)
DS	1441 (448)	1758 768)	1776 (754)	7.5
DS controls	2164 (745)	2180 (684)	2047 (678)	19.9 (15.9)
RW	1267 (223)	1530 (399)	1323 (447)	0
RW controls	2012 (843)	2039 (853)	1985 (748)	8.6 (5.4)
VE	1468 (377)	1242 (239)	1406 (394)	9.2
VE controls	2369 (1252)	2230 (1130)	2364 (1311)	12.8 (12.3)
ZV	1578 (569)	1441 (450)	1434 (393)	25
ZV controls	1768 (589)	1828 (715)	1937 (838)	22.5 (13.4)
SR	1865 (796)	1454 (300)	1722 (503)	26.7
SR controls	2761 (1495)	2632 (1411)	2503 (1263)	23.5 (12.5)

KD was fastest in the incongruent condition, although this was very similar to his RT in the 'no colour' condition, and he was slowest in the congruent condition, implying that the congruent colour caused a slight interference effect. However, the CE (32ms, with 95% confidence interval around the mean difference (CI) of -82 to 145) was not significant (t(79) = 0.6, p = .58, *d* = 0.15), when comparing the congruent and incongruent conditions. The CE for KD's control group (11ms, CI = -146 to 168) was also not found to be significant (t(648) = 0.14, p = .89, *d* = 0.01).

DS was fastest in the congruent condition, and his performance in the incongruent and 'no colour' conditions were very similar, implying that the congruent colour caused a facilitation effect. The CE (-317ms, CI = -605 to -29) was found to be significant (t(48.1) = 2.2, p=.032, *d* = 0.52), and fell outside the 95% CI range of his matched control group CE (-19ms, CI = -146 to 108). The control group's CE was not significant (t(716) = 0.29, p = .77, *d* = 0.02).

RW was fastest in the congruent condition, but was considerably slower in the incongruent condition than the 'no colour' condition, implying that the incongruent condition caused an interference effect. The CE (-246ms, CI = -397 to -131) was found to be significant (t(68.7) = 3.9, p <.001, *d* = 0.84), and fell outside the 95% CI range of her matched control group CE (-28ms, CI = -165 to 110). The control group's CE was not significant (t(816) = 0.4, p = .69, *d* = 0.03).

VE was fastest in the incongruent condition, and this was much faster than both the 'no colour' and congruent condition, suggesting that the incongruent condition had a facilitation effect. The CE (226ms, CI = 40 to 411) was found to be significant (t(24.5) = 2.5, p = .019, *d* = 0.73). The CE for VE's control group (138ms, CI = -52 to 329) was not significant (t(745) = 1.43, p = .15, *d* = 0.1).

ZV was fastest in the 'no colour' condition, and slower in the congruent condition than the incongruent condition (which was closer to the 'no colour' condition) implying that the congruent condition caused an interference effect. Although her CE (136ms, CI = -127 to 399) was not found to be significant, (t(65) = 1, p = .31) a medium effect size was found (*d* = 0.27), and her CE fell outside the 95% CI range of her matched control group (-60ms. CI = -170 to 49). The control group's CE was not significant (t(336) = 1.1, p = .28, with equal variances not assumed, *d* = 0.09).

SR was fastest in the incongruent condition, and slowest in the congruent condition which was only slightly slower than the 'no colour' condition, implying that the incongruent condition caused a facilitation effect. The CE (411ms, CI = -5 to 827) was found to be significant (t(17.6) = 2.1, p = .05, *d* = 0.75) and fell outside the 95% CI range of her matched control group (129 (-118 to 376). The control group's CE was not significant (t(656) = 1, p = .31, *d* = 0.09).

In summary, four of the six synaesthetes showed a significant difference in RT between the congruent and incongruent colour conditions, and the effect sizes for these differences ranged from medium to large. Additionally, the size of the CE for four of the six synaesthetes fell outside the 95% CI range for their group of matched controls. For the matched control groups there were no significant differences between conditions, with minimal effect sizes. The difference between the congruent and incongruent conditions was also compared individually for each of the 59 controls, as for this number of participants there should be at least three showing a significant difference by chance (when p<.05). For Control 9 for DS the congruent condition was faster than the incongruent condition (CE = -195ms, CI = -378 to -11) and this difference was found to be significant (t(93) = 2.1, p = .038, *d* = 0.5). For Control 9 for SR the congruent condition was faster than the incongruent condition (CE = 999.4ms, CI = -1932 to -67) and this difference was significant (t(47) = 2.2, p =.036, equal variances not assumed, *d* = 0.5). Therefore only two of the 59 controls (3.4%) showed a significant difference between the conditions, compared to four of the six synaesthetes (66.7%).

To further explore the difference between synaesthetes and their matched control group a modified version of the congruency effect was calculated. This involved subtracting the mean incongruent RT from the mean congruent RT, and dividing this by the ‘no colour’ mean RT to give a score standardised for different levels of baseline performance. The difference between this relative congruency effect for each synaesthete and their matched control group is shown in Figure 2.3, with a positive CE indicating that the synaesthete/group performed faster in the congruent trials than the incongruent trials, and vice versa for a negative CE. It can be seen that four of the six synaesthetes have a modified CE that is more than two standard errors above the modified CE of their associated group of matched controls.

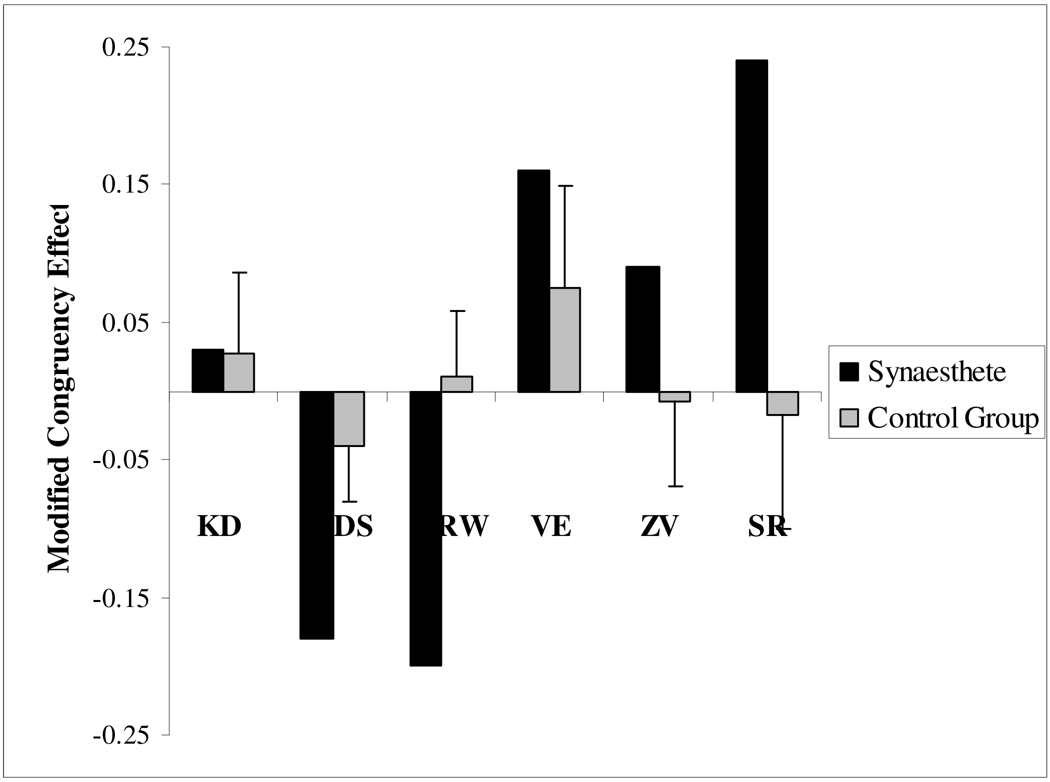


Fig 2.3: Comparison of modified congruency effect for synaesthetes and each synaesthete's corresponding group of matched controls in Experiment 1. Note: error bars show two standard errors.

Table 2.3 also shows the ER for each synaesthete and the mean ER for their associated group of matched controls. It can be seen that although there appears to be a large difference in ER between individual synaesthetes (ranging from 0% to 27%), the synaesthetes all have similar ERs to their corresponding group of matched controls (all within two standard deviations). A whole-group comparison of ERs to VVIQ scores (as shown in Table 2.1) was performed to see whether there was an association between accuracy and reported image vividness. This analysis found that the two variables were not significantly correlated (p > .05). An additional analysis was conducted to see whether a greater difference in RTs between the colour conditions would be found for synaesthetes reporting more vivid imagery than those reporting less vivid imagery. Again, a significant correlation was not found between VVIQ score and CE ($p < .05$). The participants' performance on the mental imagery task (as measured by error rate), and the effect of colour on their performance (as measured by the CE) was therefore not found to be associated with their subjective rating of vividness of imagery (as measured by the VVIQ).

2.4 –Experiment 1 Discussion

Experiment 1 has used an adapted experimental paradigm from the mental imagery literature to explore whether a synaesthetic concurrent can be elicited from a mental image of an inducer. By manipulating the colour that the grapheme was visualised against the results have shown that for four of the six synaesthetes, whether the background was incongruent or congruent with the synaesthetic concurrent elicited by that inducer had an effect on the ability to make a size-based decision about the image of the grapheme. Like previous studies exploring the visual processing of an externally presented inducer (Hubbard, Arman, Ramachandran, & Boynton, 2005; Mattingley, Payne, & Rich, 2006; Smilek, Dixon, Cudahy, & Merikle, 2001), Experiment 1 focused on the interaction between the colour of the concurrent elicited from a grapheme and the visual presentation of a 'real' colour, and the subsequent effect this interaction has on task performance. However, unlike these previous studies, Experiment 1 used an internally generated mental image of a grapheme. Importantly, for each of the matched control groups the background colour was not found to reliably affect task performance. Additionally, the reliable differences observed for the individual synaesthetes were substantially larger than the differences between colour conditions observed for the control groups, even when a modified congruency effect was used that took into account differences in the individual or groups' baseline performance. The resulting facilitation or interference in the synaesthetes' task performance caused by the colour manipulation therefore provides clear support for the synaesthetes' subjective reports that a mental image of an inducer elicits a synaesthetic concurrent.

The findings provide additional support for the idea that the external presentation of an inducer is not a requirement for the generation of a synaesthetic concurrent, as suggested by the studies exploring 'concept-driven' synaesthesia (Dixon, Smilek, Cudahy, & Merikle, 2000; Jansari, Spiller, & Redfern, 2006; Smilek, Dixon, Cudahy, & Merikle, 2002a). Importantly however, unlike the concept-driven synaesthesia studies, the task used in the current study explicitly required the generation and inspection of a mental image. In the concept-driven synaesthesia studies, the mere concept of an inducer was shown to result in a measurable synaesthetic concurrent, and this was interpreted by some as evidence to suggest that the visual processing of the inducer is not required for the synaesthetic concurrent to be elicited. However, as noted by Hubbard et al (2006) the results do not rule out the possibility that when completing the mathematical Stroop paradigm the synaesthetes generated a mental image of the digit, Hubbard et al instead suggested "top-down activation of the VWFA though mental imagery" (2006, p. 192). The current study therefore explicitly requested the synaesthetes to form a mental image of each grapheme, and used an imagery task to take a behavioural measurement of this image. It is therefore possible to speculate that the resulting synaesthetic concurrent in the current study was elicited from a mental image of the grapheme. Consequently, as concluded by Jansari et al (2006) neurocognitive models of synaesthesia such as the one proposed by Rich and Mattingley (2002) need to incorporate this. Currently the Rich and Mattingley model only explains synaesthesia from an externally presented stimulus, and so requires a way to explain synaesthesia from internally generated representations as well.

Although some neuroimaging studies with non-synaesthetes have not found activation of early visual areas with mental images of graphemes (Gulyas, 2001; Raij, 1999), it is thought that this may be due to the task demands; the requirement to make a high-resolution inspection of the image is thought to be important for activation of these early visual areas (Kosslyn & Thompson, 2003). Consequently, the imagery task used in the current study required participants to form an image of a grapheme and make a decision that required a high-resolution of detail, to increase the possibility that the image would activate early visual areas, through the use of object imagery processes. Potentially the early visual areas would have been activated by the task, resulting in a depictive representation of the grapheme being formed in these retinotopically organised areas (Kosslyn et al., 1993; Slotnick, Thompson, & Kosslyn, 2005). If synaesthetic colour is added to the grapheme-form early in the visual processing stream as suggested by proponents of the cross-activation theory (Hubbard, Manohar, & Ramachandran, 2006; Witthoft & Winawer, 2006), then activation of these early areas through this depictive representation could be imperative for the mental image of an inducer to elicit the concurrent. Evidently, without neuroimaging it is not possible to know for certain that the task was associated with activation of these early visual areas. Plus, despite the potential overlap in neural processes, it can still be argued that it was not the visual processing per se, but rather the concept of the grapheme that has induced the concurrent. Accordingly, further exploration of the role that imagery processes which do not involve activation of these early visual areas (e.g. spatial imagery processes) may play in the generation of a synaesthetic concurrent is still needed. If a synaesthetic concurrent can be elicited with a task involving spatial imagery processes, then it is still possible to argue that synaesthesia from a mental image could be concept-driven, supporting the re-entrant feedback model. However, if spatial imagery processes did not result in a measurable synaesthetic concurrent despite the concept of the grapheme being present, it would add strength to the argument that processing of the visual form is an important determining factor for the grapheme to induce the concurrent. This possibility is explored in Experiment 2.

With regards to Experiment 1 it is important to note that the difference in task performance between colour conditions was not found for all of the synaesthetes tested. The group analysis suggested that the difference between the colour conditions was very similar for both the synaesthetes and matched controls, and significant differences were only found with four of the six synaesthetes when individual synaesthetes were compared to themselves across the different conditions. Furthermore, two of the synaesthetes showing a significant colour effect were faster in the congruent condition, and two more were faster in the incongruent condition. This suggests that when visualising a grapheme whilst looking at a coloured background, the congruency of that colour to the concurrent might not affect task performance for all synaesthetes, and seemingly does not affect performance in the same way for all synaesthetes. Arguably, a mental image of a grapheme elicits a synaesthetic concurrent for only some synaesthetes. Furthermore, there were important differences in the way the concurrents influenced task performance for those synaesthetes who were shown to be affected by colour. It is therefore important to consider possible explanations for each pattern of results and also the potential individual differences that may have lead to this difference between the synaesthetes' performances.

For the synaesthetes, it was expected that a concurrent elicited from a mental image of a grapheme would result in faster performance on the imagery task when the background the grapheme was visualised against was incongruent with the colour of the synaesthetic concurrent. Two of the four synaesthetes showing a reliable difference can be seen to fit with this predicted pattern. This suggests that for these synaesthetes looking at a background colour matching the concurrent elicited by that grapheme was in some way a hindrance. An explanation for this effect is the idea that the image of the grapheme fades into the background, in a camouflage effect. This explanation fits with the findings of the Smilek et al (2001) study, which showed that a synaesthete was able to detect and identify a black target digit more efficiently when the background was incongruent with the colour experienced for the digit. This explanation however can not be used for the colour effect found with the other two synaesthetes in the current study. Interestingly though, although Smilek et al's original finding has been replicated with a different synaesthete (Smilek, Dixon, & Merikle, 2003), other research groups have been unable to replicate it. In their single-case study, Sagiv et al (2006) found that background colour manipulation actually resulted in the opposite pattern of results, so that the synaesthete was faster to detect a grapheme when the background colour was congruent with the synaesthetic concurrent elicited by the target. Sagiv et al's finding therefore reflects the unexpected direction of the colour effect found with the current study.

From the synaesthesia literature two possible explanations of this unexpected direction of effect can be found. The first comes from studies looking at the bi-directionality of grapheme-colour synaesthesia. Although it was initially reported that synaesthesia was uni-directional, i.e. that a grapheme induced a concurrent, but the same concurrent would not induce a grapheme, recent experimental studies have shown that this might not always be the case, especially at an unconscious level. These studies have shown that the presentation of a colour can evoke the concept of an inducer even in the absence of the physically presented digit (Brang, Edwards, Ramachandran, & Coulson, 2008; Cohen Kadosh & Henik, 2006; Johnson, Jepma, & de Jong, 2007). For example, a single case study by Cohen Kadosh and Henik (2006) aimed to explore whether simply presenting lines in colours that matched the synaesthetic concurrents of digits could induce a sense of magnitude. The synaesthete was shown two lines of differing lengths, and had to decide which line was longer. In the congruent colour condition the colour of the longer line was congruent with a larger digit, and the colour of the shorter line congruent with a smaller digit, whereas in the incongruent condition the longer line colour matched a smaller digit, and the shorter line colour matched a larger digit. The results showed that the synaesthetic colours did interfere with task performance, as compared to his performance in the congruent condition, the synaesthete was slower and made more errors in the incongruent condition. Although he had never experienced this in his everyday life, the synaesthete even subjectively reported that the colour of the lines evoked a perception of the corresponding digits, that is “he had a vague sensation of the digits that corresponded to the presented colours in his inner eye, but it was clear to him that he saw these digits” (2006, p. 4). The authors concluded that the congruency effect they observed in this physical comparison was likely to be due to this digit activation. Johnson et al (2007) found a similar effect using an adapted Stroop paradigm with a larger sample, showing that ‘real’ colours not only influence numerical cognition, but also activate digit related information. Interestingly however this effect was only found for two of the eight synaesthetes tested, again highlighting the heterogeneity of the synaesthete population. Taken together, the findings from these bi-directional studies can be used to speculate that synaesthetes in the current study were slower in the incongruent condition because the background colour evoked the concept of the grapheme that usually elicits this colour.

A second explanation for the faster response in the congruent condition comes from a study concerning the physiological effect of looking at an incongruently coloured grapheme (Paulsen & Laeng, 2006). This study found a difference in pupil dilation when passively viewing congruent and incongruent graphemes, which importantly was found at both a group and individual analysis level. The authors suggested that this shows that incongruently coloured inducers use more attentional processes than congruently coloured ones. This would imply that when a synaesthete views a grapheme that is incongruently coloured there would be less processing available for other tasks, such as the current imagery task. Therefore, for the synaesthetes who were slower in the incongruent condition it could be argued that this reflects a reduced processing capacity, as visualising a grapheme against an incongruently coloured background, results in similar perceptual processing as passively viewing an incongruently coloured inducer. Additional support for this idea comes from an fMRI study looking at the neural correlates of incongruently coloured graphemes that reported activation that has previously been shown to involve cognitive control processes (Weiss, Zilles, & Fink, 2005), again suggesting that incongruent stimuli may use more of the available processing resources than congruent stimuli.

As mentioned earlier, two of the six synaesthetes in the current study did not show a significant effect of colour. Interestingly however, both synaesthetes who did not show a significant effect of colour did subjectively report that a mental image of an inducer elicits a concurrent. Consequently, when considering the current findings, a Type II statistical error is a possibility, as it may be that for some synaesthetes there was not enough statistical power to produce a significant result. This possibility is especially strong for ZV who had a substantially larger difference between conditions than her group of matched controls. Importantly however, a third study has attempted to replicate Smilek et al's (2001) camouflage effect. Blake et al (2005) found that their synaesthete showed no significant affect of background colour, although their task was a vowel-consonant decision task rather than the visual search paradigm used by Smilek and colleagues (2001; 2003) and Sagiv et al (2006). Blake et al's results are important however, as they again reflect the magnitude of individual differences within the synaesthete population (as also shown by Johnson et al, 2007). The current study has the advantage of not being a single-case study, and by not relying only on the group-level analysis, the individual level analysis has revealed that the background colour manipulation paradigm does not have the same affect on task performance for all synaesthetes. When completing the imagery task the background colour had no effect for some synaesthetes, whereas for others a congruent background facilitated performance, and again for others this was a hindrance. The heterogeneity of synaesthetes has been recognised in recent studies (Hubbard, Arman, Ramachandran, & Boynton, 2005), and the current study adds further support to the idea that there are important individual differences between synaesthetes, and differences in the effect their synaesthesia has on performance in behavioural tasks.

Consequently, it is important to use evidence from the mental imagery and synaesthesia literatures to speculate about reasons for the lack of group effect. One possible explanation concerns individual differences within the synaesthete population. For example, synaesthetes' reports of the spatial location in which the concurrent is experienced has been used to classify two 'types' of synaesthetes; 'projectors' who experience the concurrent in an external spatial location and 'associators' who experience the concurrent as an internal experience (Dixon, Smilek, & Merikle, 2004). It has been suggested that there are stable differences in performance between these types of synaesthesia on behavioural tasks. In relation to the current study, it might be expected that a mental image of a grapheme would be likely to elicit a synaesthetic concurrent for a 'projector' as long as the mental image was 'percept-like' enough in order for the colour to be projected onto the shape of the grapheme. Therefore the prediction would be that projectors in the study would show a clear colour effect, as the concurrent would be expected to 'camouflage' their mental image, making the size-based decision more difficult in the congruent condition. However, with the data available it would appear that this purported difference between types of synaesthetes does not explain the mixed pattern of results from the current study. For example, a significant effect of colour was found for one of the projector synaesthetes, but it was not found for the other (see Table 2.1). It is therefore not possible to use this distinction to explain the difference in results found with the current study. It is also important to note that this division has since been questioned, as the synaesthetes' subjective reports of their phenomenological experiences has been shown to lack reliability (Edquist, Rich, Brinkman, & Mattingley, 2006) and the initial findings of Dixon et al were not supported by a recent replication with a different sample of synaesthetes (Ward, Li, Salih, & Sagiv, 2006).

Another possible explanation for the lack of group effect comes from the mental imagery literature, and concerns individual differences in imagery ability. This explanation implies that a synaesthete needs to create a vivid mental image of a grapheme in order for it to elicit a synaesthetic concurrent, as a less vivid image would not trigger the cascade of neural processing needed for the synaesthetic colour to arise (Grossenbacher & Lovelace, 2001). This fits with the idea within the mental imagery literature that in order for the early retinotopically organised visual areas to be activated, the mental image needs to have a high resolution level of detail (Kosslyn & Thompson, 2003), and activation in this area is thought to play a functional role in image generation (Kosslyn, Thompson, Kim, Rauch, & Alpert, 1996). The neuroimaging studies exploring activation of primary visual cortex with imagery tasks often report substantial individual differences; for example, only half of the participants showed activation of early visual cortex in Slotnick et al's (2005) study, but the authors argued that "individual differences in imagery ability permeate the literature and are the norm in neuroimaging studies of imagery" (2005, p. 1581). Klein et al (2004) also found substantial individual differences, and suggested that these may be related to the 'efficacy of underlying information processes' as the earlier mentioned PET study exploring the neural correlates of mental imagery showed a correlation between the level of rCBF in this area and the time taken to perform the imagery task (Kosslyn, Thompson, Kim, Rauch, & Alpert, 1996). As a potential measurement of imagery ability, the VVIQ was completed by all participants in Experiment 1. However, as a significant correlation between congruency effect and the VVIQ score was not found it can be implied that image vividness was not related to the difference between synaesthetes. The two synaesthetes who did not show a significant difference between the colour conditions did not report particularly high or low VVIQ score in comparison to the other synaesthetes. Still, it needs to be noted that the VVIQ asks participants to rate the vividness of images of detailed scenes rather than individual graphemes so it is potentially limited in its application to the current study. The VVIQ score was also not found to be correlated with accuracy in the current task, which further suggests its limited application, as it would be expected that participants (both synaesthetes and matched controls) who report less vivid imagery would have higher error rates on an imagery task.

A final difference to consider for Experiment 1 would be the individual synaesthete's approach to the task. The imagery task used involves cognitive effort, and as such synaesthetes may have approached task completion in different ways. Support for this idea comes from a study looking at the memory of synaesthetes, which asked synaesthetes to memorise matrices of numbers that were either congruently or incongruently coloured (Yaro & Ward, 2007). Unlike a previous single-case study that had used this paradigm (Smilek, Dixon, Cudahy, & Merikle, 2002b) Yaro and Ward did not find that the synaesthetes more accurately recalled the congruently coloured matrices than the incongruently coloured matrices. Interestingly for the current study, the debriefing of the synaesthetes in the Yaro and Ward study found that the congruency of the colours had a variety of reported effects. Some synaesthetes reported the incongruent colours acted as a distractor, whereas others stated that they just ignored the visual colour and focused on their synaesthetic colour to aid their memorisation. Additionally other synaesthetes reported that the congruent colour could act as a distractor, as they seemed to “spend more time enjoying the digits presented in the appropriate colour than attempting to memorise them” (2007, pp. 688-689). Consequently, in relation to Experiment 1 the congruent and incongruent backgrounds may have acted as either a distractor (“it’s so nice to see the right colour”) or attracted additional visual attention (“it looks weird having the wrong colour and draws my attention”).

The amount of attention a synaesthete gave to each mental image may subsequently have had an effect on the associated neural processing. The findings from an fMRI study looking at the impact of the semantic content of mental images on the associated neural processing can offer a possible explanation for this difference in effect between synaesthetes. Mazard et al (2005) compared activation in visual areas for mental images of objects to mental images of non-objects (abstract shapes), hypothesising that there would be more activation in primary visual cortex with the images of non-objects as these would be more difficult to form from memory. Surprisingly however, there was slightly more activation when forming images of the objects than non-objects. The authors suggested that this was not due to image complexity as the objects and non-objects were carefully matched. Instead they proposed that it could be due to the amount of attention paid to the image, as the amount of activity in these areas had previously been shown to be associated with visual attention in visual perception studies (Kanwisher & Wojciulik, 2000). It was suggested that as the objects were inherently more interesting than the non-object images, which were just abstract shapes, the participants paid more visual attention to them, and this enhanced visual attention could have caused the greater activation found with the object images. In relation to the current study, enhanced attention to the mental image of the grapheme could also lead to greater activation in early visual areas. This additional visual attention could then result in the greater activation of early visual areas, leading to better task performance. Therefore, these kinds of differences in the subjective experience of being presented with a colour, and being asked to visualise a particular grapheme, could also be a possible explanation for the differences in effect found with the current study.

Summary of Experiment 1

Experiment 1 aimed to explore the possibility of measuring a synaesthetic concurrent from a mental image, using a novel combination of a paradigm from the mental imagery literature and a paradigm from the synaesthesia literature. It was hypothesised that synaesthetes would make faster size-based decisions about a mental image of a grapheme when it was visualised against an incongruently coloured background than when congruent. The results showed that for four of the six synaesthetes tested there was a significant difference in task performance, but the direction of the hypothesis was only supported with two of the synaesthetes. This difference in the direction highlights the heterogeneity within the synaesthete population, and possible explanations for this, such as differences in synaesthesia and differences in imagery ability have been considered. Although with the data available a complete post hoc explanation was not possible, it seems that individual differences in the amount of visual attention paid to either the congruent or incongruent background colour could also be a possible explanation. The main focus of Experiment 1, however, was to provide objective evidence of a synaesthetic concurrent elicited from a mental image of a grapheme. To this end, the current study has provided this support. Additionally, due to the demands of the imagery task used it is possible to argue that the mental images had percept-like qualities, and that the object imagery processes potentially activated the early visual areas. This therefore goes some way to suggesting the synaesthetic concurrent found with the concept-driven synaesthesia studies may have been elicited from a mental image of a grapheme, rather than the mere concept alone. However, further exploration is needed, as the synaesthetic concurrent elicited with the current imagery task may still have been driven by the concept rather than the grapheme-form depicted in the mental image. This issue will be explored further in Experiment 2.

Chapter 3 – Generating a synaesthetic concurrent from a mental image of a grapheme: the role of spatial imagery processes (Experiment 2)

3.1 – Experiment 2 Introduction

Experiment 1 provided empirical support for the idea that, for some synaesthetes, a mental image of a grapheme can elicit a synaesthetic concurrent. The task involved generating an image of a grapheme and then making a size-based decision about the grapheme in the image that was visualised against a coloured background. Whether the background colour was congruent or incongruent with the synaesthetic colour of the grapheme being visualised was shown to affect task performance for some synaesthetes. The task was thought to use object imagery processes, and was chosen for the previous study because it purportedly involved the generation and inspection of a high resolution image. Therefore the task may potentially have used similar neural mechanisms as those used in visual perception of a grapheme, including activation of early visual areas. However, object imagery is not the only type of imagery process. Consequently, in order to investigate mental imagery and synaesthesia further, Experiment 2 was designed to explore whether a synaesthetic concurrent could be measured with a task utilising spatial imagery processes. As mentioned earlier, spatial imagery processes are thought to use the dorsal visual pathway, and so do not necessarily involve the processing of the grapheme form. If a concurrent was found to be elicited from a mental image of a grapheme using spatial imagery processes, as it has been with object imagery processes, then it would be possible to speculate that the processing of the grapheme-form is not a determinant of the synaesthetic concurrent. This would provide support for the re-entrant feedback model of grapheme-colour synaesthesia. However, if spatial processes were not found to elicit a concurrent then this would add support to the proposal that processing the grapheme-form in early visual areas is an important determinant of the synaesthetic concurrent, providing support for the cross-activation theory of grapheme-colour synaesthesia.

Spatial imagery processes

As outlined in Chapter 1, spatial imagery is thought to be processed through the dorsal pathway, which registers spatial properties of an object such as its location and size (Ungerleider & Mishkin, 1982). This pathway runs from the occipital lobes to the parietal lobes, and difficulties in spatial processing can be a consequence of damage to this region (Levine, Warach, & Farah, 1985). Additionally, as discussed in Chapter 1, damage to the parietal lobes in particular can result in damage to spatial attention (Robertson, 2003). Although both the ventral and dorsal pathways generally process object and spatial information concurrently, specific imagery tasks are thought to rely more on one particular pathway. While the task used in Experiment 1 purportedly relied more on object imagery processes, mental rotation tasks are well documented to rely on spatial imagery processes (Kosslyn et al., 2004). The first main study to explore mental rotation used abstract three-dimensional (3D) pictures of blocks (Shepard & Metzler, 1971). Participants were shown a pair of abstract blocks and had to decide whether the two were the same, with one being rotated at a different angle from the other, or if they were different. The authors found that response times increased as the angle of rotation increased, and that there was a linear relationship between the two variables. These results, they suggested, illustrated how in order to compare the two objects, participants mentally transformed one into the other – a process they termed 'mental rotation'. A subsequent study used graphemes, to see if mental rotation would also be required with these highly learned stimuli (Cooper & Shepard, 1973). When presented with a grapheme, rotated away from the upright position, participants decided whether it was a 'normal' presentation of the grapheme, or a 'backwards' or mirrored version. Again, it was found that as degree of rotation from the upright position increased, so did response time, with response time increasing until the grapheme was rotated by 180^0, and then symmetrically decreasing after that. The general conclusion from these and subsequent studies was that these tasks required participants to mentally rotate an object within a mental image, in the same way as one might imagine rotating a physical object, because as the angle of rotation increased, so did the amount of time it took to respond.

The parietal cortex has consistently been shown to be associated with mental rotation tasks. For example, an fMRI study looking at cortical activation during mental rotation of different stimuli (such as letters, 3D blocks and abstract shapes) found that compared to the baseline task, regardless of the visual object being mentally rotated, all of the mental rotation tasks showed only significant activation within the parietal core regions (Jordan, Heinze, Lutz, Kanowski, & Jancke, 2001). This activation was bilateral in the superior and inferior parietal lobe, and was specifically focused in the intraparietal sulcus (IPS). These findings are consistent with studies of patients with brain damage to the parietal region which have shown deficits in mental rotation ability

(Ditunno & Mann, 1990). Furthermore, a recent TMS study demonstrated the functional role that the parietal lobes contribute to mental rotation ability (Harris & Miniussi, 2003). These findings have therefore collectively been used to suggest that mental rotation makes use of spatial representations, such as those used for navigation, rather than visual ones. This is further supported by the finding that parts of the posterior parietal lobes are topographically organised (Sereno, Pitzalis, & Martinez, 2001), which could be important for representing the spatial layout of images (Borst & Kosslyn, 2008).

The body of research concerning mental rotation tasks can therefore be used to support the idea that a potential paradigm for assessing the generation of a concurrent using spatial imagery processes is a mental rotation paradigm. A suitable design is one that has been used previously by Alivisatos and Petrides (1997) to explore the functional brain activation during mental rotation of graphemes, and also been adapted by Harris et al (2000). In the original version there were two visuo-spatial tasks: Task 1 was a mirror-image discrimination task, in which participants were shown upright graphemes in either ‘normal’ or ‘backwards’ format (see Figure 3.1). Task 2 was essentially the same as this, but the stimuli were rotated to three different angles of rotation (see Figure 3.2). In each task participants had to decide whether the grapheme was “normal” or “backwards”. Consequently, in Task 2 participants were instructed to mentally rotate the grapheme to the upright position before making their decision, whereas in Task 1 mental rotation was not needed. In their comparison of rCBF with these two tasks in the non-synaesthete population, Alivisatos and Petrides (1997) found similar parietal activation in both the mirror-image discrimination task (Task 1) and the mental rotation task (Task 2).

Compared to a control condition, both tasks showed increased rCBF in the inferior parietal lobule of the left hemisphere. Therefore, although Task 1 did not require actual mental rotation of the grapheme it can be seen that it did require some mental transformation of the stimuli. The main difference found between two tasks was that the additional mental rotation demands of Task 2 showed greater activation in the left parietal region.

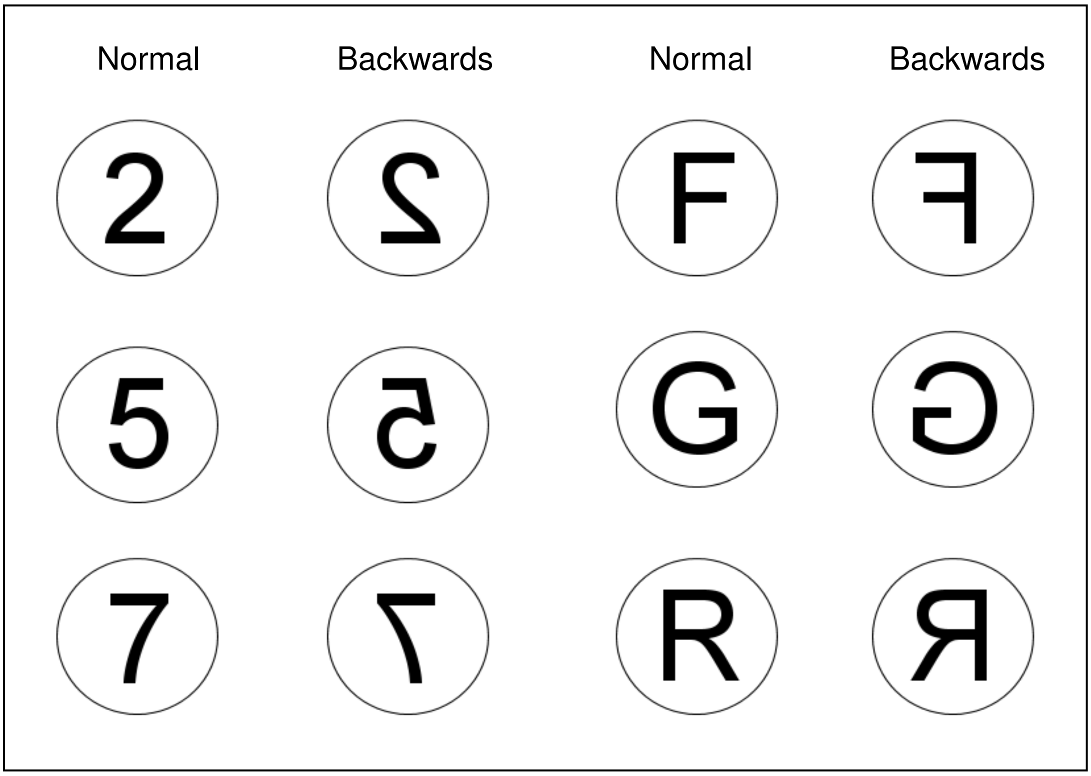


Fig 3.1: Target stimuli for Task 1 (Experiment 2) presented in ‘normal’ and ‘backwards’ format

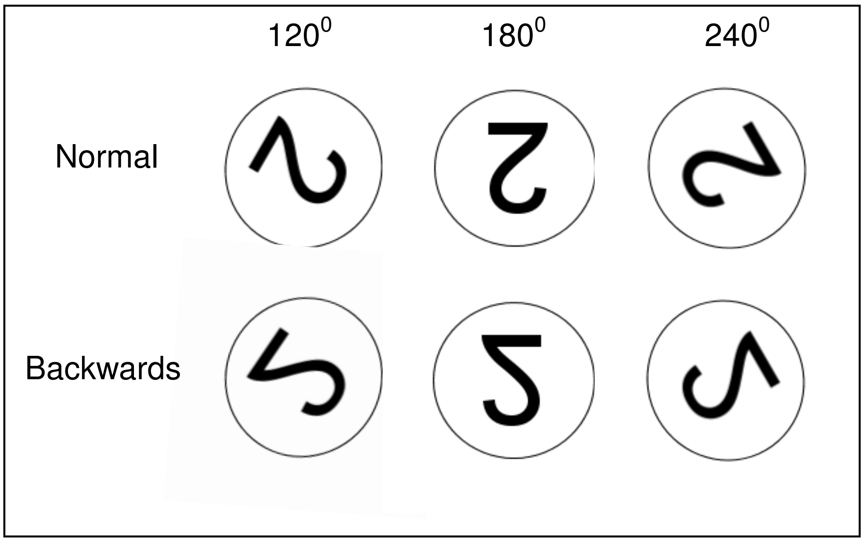


Fig 3.2: Example of Task 2 (Experiment 2) target stimuli, presented in ‘normal’ and ‘backwards’ format, rotated 120^0, 180^0, and 240^0 from the upright position

Consequently, it was decided that both tasks would be suitable for use in Experiment 2, to see whether a synaesthetic concurrent would be elicited with a straight-forward mirror-image discrimination task, and then whether the additional mental rotation process would further affect the processing of the synaesthetic concurrent. For both tasks, the dependent variable was the time taken to decide whether the grapheme was ‘normal’ or ‘backwards’ (response time for correct responses only). The original tasks were adapted however, to include a colour variable, with a congruent, incongruent, and ‘no colour’ condition; the graphemes were presented in the colour of the concurrent associated with the grapheme, a colour not associated with the grapheme, or achromatic (grey) respectively. If a synaesthetic concurrent was elicited from a grapheme during either task, it was expected that the interaction between the ‘real’ colour of the grapheme and the synaesthetic concurrent would affect task performance, as suggested by other studies exploring the visual processing involved in synaesthesia (for example, Smilek, Dixon, Cudahy, & Merikle, 2001). For non-synaesthetes however, colour of the graphemes would not be expected to have a reliable effect on task performance.

For both Task 1 and 2 it was predicted that synaesthetes would be slower in the incongruent condition, resulting in a negative congruency effect when using the congruency minus incongruency formula used in Experiment 1. This prediction was based on the idea that the perceptual mismatch of viewing incongruently coloured graphemes would result in the availability of fewer processing resources than when viewing congruently coloured graphemes. As suggested earlier, previous synaesthesia research has shown viewing incongruently coloured inducers to be associated with activation of cortical areas thought to be involved in cognitive control mechanisms (Weiss, Zilles, & Fink, 2005), suggesting that viewing incongruently coloured inducers requires cognitive effort. This idea is also supported by the finding that passively viewing incongruently coloured inducers is associated with increased pupil dilation, which can be used as a measure of increased attentional demand (Paulsen & Laeng, 2006). Consequently, when processing resources are used to process task irrelevant material, there should be fewer resources available to process task relevant material.

Additionally, both the format the grapheme was presented in and the angle of rotation required could also have an impact on the expected colour effect, for both Tasks 1 and 2. With regards to the grapheme format, if the visual percept, rather than the concept, of the grapheme is important for the concurrent to be elicited as suggested by Hubbard et al (2006) it was expected that the congruency effect would be larger for trials in which the grapheme was presented in the normal format than when presented in backwards format. However, another reason to expect a difference in congruency effect for the different formats was the difference expected in response latency between formats and angles of rotation. Previous studies, with the non-synaesthete population, have shown that even when a grapheme is shown in the upright position, participants take longer in trials when the grapheme is presented in 'backwards' format than when presented in 'normal' format (for example Cooper and Shepard (1973) reported a main effect of grapheme format). This slower response time has been explained with the idea that participants need to make an additional "mental flip" on the vertical axis to normalise the backwards graphemes which is not needed with the normal graphemes (Hamm, Johnson, & Corballis, 2004). Therefore, greater cognitive effort would be required for the backwards graphemes in Task 1 and 2. Similarly, with Task 2 the co-variable of angle of rotation (i.e. the angle the grapheme was rotated away from the upright position; 120^0, 180^0, or 240^0) could have an effect on the subsequent generation of a concurrent. As noted earlier, studies have found that the response latency is also related to the angle of rotation required, such that larger angles of rotation have been shown to take more time than smaller angles of rotation (Cooper & Shepard, 1973). Consequently it can be argued that the trials with backward graphemes or graphemes requiring a greater angle of rotation necessitate more cognitive effort.

Based on studies of attention and synaesthesia (as outlined in Chapter 1), it was therefore hypothesised that the increase in attentional demand, either with the backwards graphemes or the larger angles of rotation, would result in a smaller congruency effect. This is because it has been suggest that increased attentional demands can decrease the strength of the synaesthetic concurrent (as measured by the effect on task performance) (Mattingley, Payne, & Rich, 2006). Mattingley et al found that when synaesthetes completed a distractor task with high-attentional demands the subsequent effect of the synaesthetic concurrent on a Stroop task was less pronounced, than when the synaesthetes completed a task with low-attentional demands. Using the logic of Lavie (1995) they concluded that this was due to the availability of processing resources; Lavie had previously shown that due to the limited processing capacity of visual processing, when a distractor task had high-attentional demands there were fewer resources available to process visual material that was irrelevant to task completion. Therefore in relation to Experiment 2, when the trials required greater levels of attention it was expected that there would be fewer resources available to process the colour of the grapheme (with the concurrent as the irrelevant visual material), resulting in less conflict between the synaesthetic concurrent and the 'real' colour. However, in trials that required less attention, for example when the grapheme was presented in normal format or required a smaller angle of rotation, the congruency effect would be expected to be stronger as there would be more processing resources available to process task irrelevant material. A summary of the predicted effects and interactions for both Task 1 and Task 2 is given in Table 3.1.

Table 3.1: Summary of predicted effects and interactions for Task 1 and Task 2 in Experiment 2

	Predicted effect	**Predicted direction**
Task 1	Format effect (for all participants)	‘Backwards’ graphemes slower than ‘normal’
	Colour effect (for synaesthetes only)	Incongruent graphemes slower than congruent
	Format x colour interaction (for synaesthetes only)	Greater CE for “normal” than ‘backwards’ graphemes (due to limited processing capacity for colour as an irrelevant stimuli feature)
Task 2	Format effect (for all participants)	‘Backwards’ graphemes slower than ‘normal’
	Angle effect (for all participants)	larger angle of rotation slower than smaller angles of rotation
	Colour effect (for synaesthetes only)	Incongruent graphemes slower than congruent
	Format x angle x colour interaction (for synaesthetes only)	Greater CE for graphemes in ‘normal’ that require smaller angles of rotation (due to limited processing capacity for colour as a irrelevant stimuli feature)

3.2: Experiment 2 Method

Participants

In the current study there were four grapheme-colour synaesthete participants and a new group of 10 age and gender matched controls for each of the synaesthetes. All participants were over 18 years of age, had normal visual acuity (or corrected to normal) and were in good mental health according to self report.

Four of the six grapheme-colour synaesthetes who participated in Experiment 1 were recruited for Experiment 2; these were KD, DS, RW and VE. See Table 2.1 for details of their synaesthesia.

As before, the newly recruited matched controls were assessed for synaesthesia. As none of the controls reported any synaesthesia-like experiences, the data for all 40 controls was included in the analysis. The mean age of the synaesthetes (35.5, SD = 12) and the mean age of the controls (35.6, SD = 11.5) did not differ significantly (t (42) = 0.008, p >.05, *d* = 0.004). The VVIQ score was also not found to differ significantly between the synaesthetes (78, SD = 9) and the controls (79, SD = 23), (t (42) = 0.15, p<.05, *d* = 0.11). Table 3.2 summarises the characteristics of the synaesthetes and their matched controls

Table 3.2: Participant demographics for synaesthetes and each synaesthete's corresponding group of matched controls in Experiment 2, including each synaesthete's modified Test of Genuineness (Baron-Cohen, Wyke, & Binnie, 1987) test-retest reliability percentage (ToG %), location of colour experience ('projector' or 'associator'), comparison of colour vividness from written/imagined graphemes, and each synaesthetes' actual and control groups' mean score on the Vividness of Visual Imagery Quota (VVIQ; Marks, 1973)

Synaesthetes							**Matched Control Group**	
ID	*Gender*	*Age*	*ToG %*	*VVIQ Total*	*Colour location*	*More vivid experience from written/ imagined graphemes*	*Age Mean (SD)*	*VVIQ Mean Total (SD)*
KD	male	40	94	66	associator	imagined	40 (3.2)	84 (23)
DS	male	29	94	76	associator	written	27.5 (3.7)	82 (21)
RW	female	50	100	81	associator	imagined	51.3 (3.6)	78 (26)
VE	female	23	100	88	projector	written	23.4 (2.7)	73 (18)

Materials

The two tasks were run on a PC using the software E-Prime. As used by Alivisatos and Petrides (1997), the stimuli were three asymmetrical uppercase letters and three asymmetrical digits, presented in both their 'normal' format and 'backwards' (a mirror version of the normal) format (see Figure 3.1 and 3.2). The same stimuli for each synaesthete were used in Task 1 and Task 2, except in Task 2 they were rotated 120^0, 180^0, or 240^0 away from the upright position.

The three angles of rotation were the same as those used by Alivisatos & Petrides (1997), which they had chosen because they were found to be the more difficult angles from a previous study (Alivisatos, 1992). For each synaesthete the stimuli were individually designed so that the congruent and incongruent conditions used appropriate colours, based on the colour information given in the pre-test assessment (see Procedure). The stimuli used were F, G, R, 2, 5, and 7 when possible. However, if the synaesthete's colour for one of these graphemes was unsuitable for use (e.g. too light to be visible on a white computer screen) then an alternative was used. This happened for VE (R was replaced with a P), and RW (2 was replaced with a 4 and R was replaced with a P). Each grapheme was presented in the centre of a white computer screen within a black outline of a circle.

Procedure

Pre-study assessment: The same pre-study assessment as used for the synaesthete participants in Experiment 1 was used in the current study. This involved providing a visual representation of the concurrent elicited by each grapheme, and rating the strength of each concurrent (see Chapter 2 for details).

Task 1: Participants received both spoken and written instructions on the computer for Task 1 (see Appendix B), and were sat in front of a computer screen, and held a microphone in their hand. Before completing the main block of trials, participants were shown the six graphemes that would be used in the task, in their upright positions. Participants completed six practice trials, before starting the main set of trials. In each trial a fixation mark was seen in the centre of the computer screen for 1500ms, which was followed by the presentation of a target stimulus. The target stimulus was a grapheme presented in either ‘normal’ or ‘backwards’ format. Participants had to decide as quickly as possible without sacrificing accuracy which format the stimulus was in. Participants gave a spoken response into a hand-held microphone, saying either ‘normal’ or ‘backwards’. The computer recorded the response time for each trial and their choice of response was noted by the experimenter. When the spoken answer was given the next trial began. There was a maximum of 2500ms for each trial, and if a response was not given within the time allowed the trial was recorded as a ‘timeout’.

The stimuli were presented in ‘normal’ format 50% of the time, and ‘backward’ format 50% of the time. The stimuli were black or congruent or incongruent with the synaesthete’s colour for that grapheme, with an equal number of each. The incongruent colours were chosen from the colours experienced by another synaesthete for each stimulus, ensuring that the incongruent colour was sufficiently different from the congruent colour. With six different stimuli, three different colour conditions (congruent, incongruent and no colour) and two different formats (normal and backwards), there were 36 possible stimuli. In total Task 1 had 72 trials, so that each stimulus was used twice (except for VE for whom there were a total of 36 trials due to computer error). The trials were presented in a random order.

Task 2: The procedure for Task 2 was essentially the same as it was for Task 1 but participants were told that in this task the graphemes would be rotated away from the upright position. Therefore in order to work out whether the target stimulus was in 'normal' or 'backwards' format they were instructed to mentally rotate the stimulus to the upright position to work out the answer (see Appendix B). Participants were also reminded that they needed to respond as quickly as possible, without sacrificing accuracy, and that there was a maximum of 2500ms per trial to make the response before the computer would move on to the next trial (such 'no response' trials were again recorded as 'timeouts'). In total there were 108 trials, with six different stimuli, three different colours (congruent, incongruent and no colour), two different formats (normal and backwards) and three different angles of rotation (120^0, 180^0, or 240^0 away from the upright position). Each of the stimuli were shown once in a random order.

3.3: Experiment 2 Results

Task 1

Comparison of groups: To explore the effect of colour on task performance outliers were removed (as calculated with stem and leaf procedures using SPSS version 15, not including timeouts). This resulted in between 4% and 6% of trials being removed for synaesthetes (mean = 6%), and between 0% and 15% for control participants (mean = 5%). All but one participant had a 100% accuracy rate. The mean response time (RT) for each participant in each condition was calculated for correct responses. Table 3.3 shows the mean RTs for the synaesthetes (n=4) and controls (n=40).

Table 3.3: Mean response times (RTs in ms) in Task 1 of Experiment 2 as a function of colour condition (congruent, incongruent and 'no colour') with standard deviations (SD) in parentheses.

	Mean RT (ms) and SD in colour condition		
Group	**Congruent**	**Incongruent**	**No Colour**
Synaesthetes	697 (88)	765 (77)	716 (50)
Controls	683 (111)	699 (135)	684 (122)

A repeated measures ANOVA with 'colour' (congruent, incongruent and no colour) as the within-group factor and 'group' (synaesthete and controls) as the between-group factor found a significant effect of colour (F(1.7, 72.4) = 3.8, p= .033, η^2 = .08), no effect of group, and no interaction between these factors (ps <.05). For both synaesthetes and controls the slowest response was in the incongruent condition. As a group, the mean congruency effect (CE, mean congruent RT – mean incongruent RT) for the synaesthetes (-68, SD = 44.3) was significantly larger than the mean CE for the controls (-16, SD = 50), (t(42) = 1.99, p = .05, *d* = 1.1). The mean timeout frequencies were very similar for the two groups (1.25, SD = 1.9 for synaesthetes and 1.23, SD = 2.5 for controls) and this difference was not statistically reliable (p <.05).

Comparison of each synaesthete to their matched control group: As with the analysis in Experiment 1, the performance of each individual synaesthete was compared to their associated group of matched controls in order to explore the effect of colour on performance in more detail. Mean RTs for trials with correct responses for each condition were calculated for each synaesthete and each group of controls, as shown in Table 3.4.

Table 3.4: Mean response times (RTs) in Task 1 of Experiment 2 as a function of colour condition (congruent, incongruent and no colour), and timeout frequency for synaesthetes and each synaesthete's corresponding group of matched controls (standard deviations in parentheses).

	Mean RT (ms) and SD in colour condition			**Mean Timeout Frequency**
	Congruent	**Incongruent**	**No Colour**	
KD	629 (127)	716 (200)	753 (213)	4
KD controls	672 (145)	699 (167)	680 (157)	2 (2.3)
DS	805 (233)	815 (198)	757 (252)	1
DS controls	646 (125)	650 (136)	646 (153)	0.3 (1)
RW	622 (59)	685 (105)	651 (163)	0
RW controls	702 (183)	710 (174)	712 (196)	1.5 (3.8)
VE	732 (73)	845 (204)	703 (97)	0
VE controls	680 (160)	678 (166)	693 (179)	1.1 (2.1)

The graphemes in Task 1 were presented in both normal and backwards format, and so the effect of colour on task performance was explored with a 3x2 ANOVA with colour (congruent, incongruent and no colour) and grapheme format (normal and backwards) as the between-group variables. For KD this revealed a significant effect of colour (F(2, 58) = 3.23, p = .047, η^2 = .1), no significant effect of format (F (1, 58) = 0.07, p = .79, η^2 = .001), and a significant interaction between colour and format (F(2, 58) = 3.77, p = .029, η^2 = .03).

Post-hoc Games Howell comparisons of the colour conditions showed that the colour effect was driven by a faster response in the congruent condition than the ‘no colour’ condition (p = .07). However, the interaction, as shown in Figure 3.3, suggests that while in the trials in backwards format there was little difference in RT for the three colour conditions, in the trials with normal format there was a big difference between RTs for the three colour conditions. In the congruent condition KD was fastest with graphemes in normal format, whereas in the ‘no colour’ condition he was faster with graphemes in backwards format (and to a lesser extent in the incongruent condition). There were no significant effects or interaction for KD’s control group.

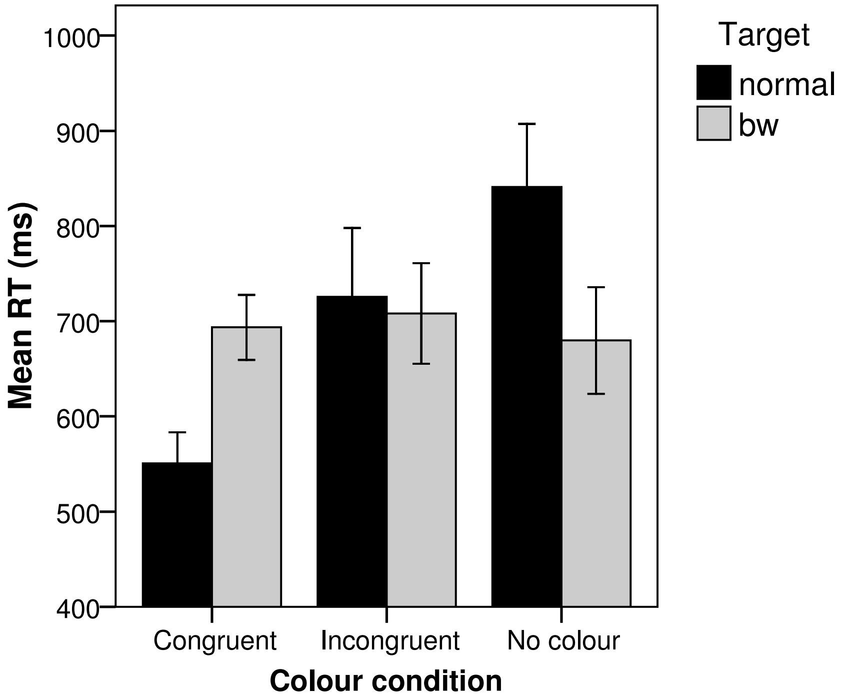


Fig 3.3: Interaction between colour condition (congruent, incongruent and no colour) and grapheme format (normal and backwards) for KD in Task 1 of Experiment 2 (with error bars showing 1 standard error).

For VE a significant effect of colour (F(2, 28) = 5.11, p = .013, η^2 = .27) and format (F (1, 28) = 8.62, p = .01, η^2 = .24), and a significant interaction between the two (F(2, 28) = 4.47, p = .021, η^2 = .24) were found. The main effect of colour was driven by a faster response to trials in the 'no colour' condition than the incongruent condition (703ms compared to 845ms, although with Games-Howell post-hoc comparisons p = .11), and the main effect of format was driven by a faster response to normal trials than backwards trials (701ms compared to 823ms). However, the interaction, as shown in Figure 3.4, suggests that with the trials in backwards format she was particularly slowed in the incongruent condition than either the congruent or 'no colour' conditions. For VE's control group there was a significant effect of format (F(1, 682) = 4.93, p = .03, η^2 = .01), no main effect of colour, and no interaction; a comparison of the grapheme formats showed that VE's controls were faster with the backwards format (669ms, SD = 158) than the normal format (698ms, SD = 177).

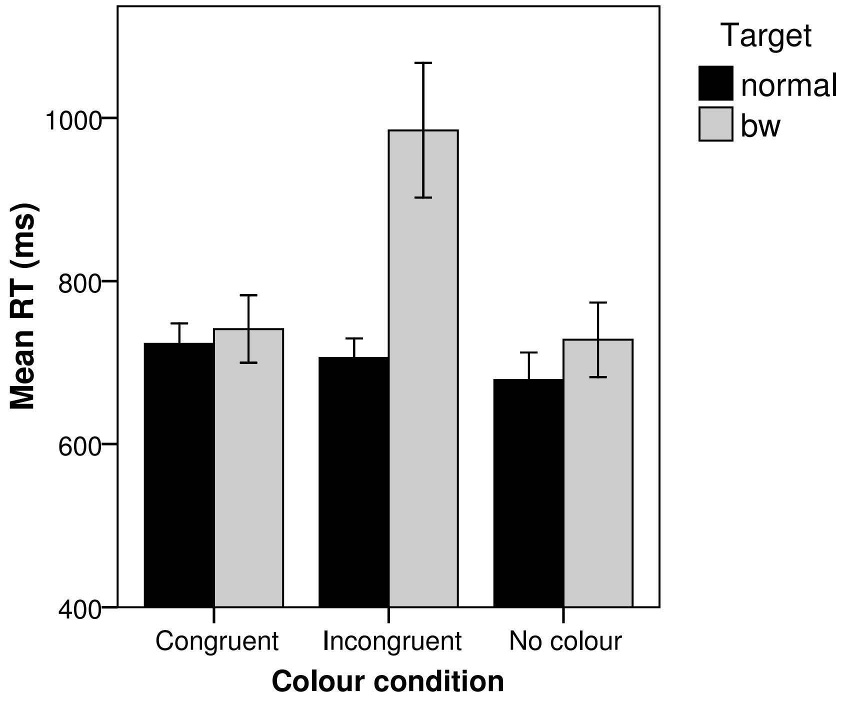


Fig 3.4: Interaction between colour condition (congruent, incongruent and no colour) and grapheme format (normal and backwards) for VE in Task 1 of Experiment 2 (with error bars showing 1 standard error).

For DS there was no significant effect of colour, format or interaction, while for his control group there was a significant effect of format (F (1, 683) = 4.45, p = .035, η^2 = .01), no effect of colour (F (2, 683) = 0.1, p = .94, $\eta^2 < .001$), and no interaction (F (2, 683) = 0.5, p = .6, η^2 = .001). The control group responded faster when graphemes were presented in backwards format (637ms, SD = 129) than normal format (659ms, SD = 146). For RW and her control group there was no significant effect of colour, format or interaction.

Table 3.4 also shows the timeout frequencies for each synaesthete and the mean timeout frequency for their associated group of matched controls. It can be seen that for both the synaesthetes and their matched control groups the timeout frequencies are low (ranging from 0 to 4), and there is little difference either between synaesthetes, or between synaesthete and matched control groups. Therefore, the timeout frequencies for the different colour conditions are not found to differ to any significant extent (and so data are not shown). A whole group analysis of timeout frequencies to VVIQ scores (as shown in Table 3.1) was performed to see whether there was an association between subjective image vividness and the timeouts. This analysis found that the two variables were not significantly correlated ($p < .05$).

Task 2

Comparison of groups: To explore the effect of colour on performance in Task 2 again outliers were removed (as calculated with stem and leaf procedures using SPSS version 15, not including timeouts). This resulted in 7% being removed for all synaesthetes, and between 0% and 10% for control participants (mean = 4%). The mean response time for each participant in each condition was then calculated for correct responses. Table 3.5 shows the mean RTs for the synaesthetes (n=4) and controls (n=40).

Table 3.5: Mean response times (RTs in ms) in Task 2 of Experiment 2 as a function of group and of colour condition (congruent, incongruent and ‘no colour’) with standard deviations (SD) in parentheses.

	Mean RT (ms) and SD in colour condition		
Group	**Congruent**	**Incongruent**	**No Colour**
Synaesthetes	1047 (227)	1012 (170)	968 (124)
Controls	1162 (232)	1159 (242)	1161 (213)

A repeated measures ANOVA with ‘colour’ (congruent, incongruent and no colour) as the within-group factor and ‘group’ (synaesthete and controls) as the between-group factor did not find a significant effect of colour or group, or a significant interaction between these factors. As a group the mean CE for the synaesthetes (35ms, SD = 94) did not differ significantly from the mean CE for the controls (3ms, SD = 96). Although the mean timeout frequencies for the synaesthetes (3.5, SD = 4.4) was slightly lower than the controls (7.8, SD = 9.6), and the mean error rates were also lower for the synaesthetes (5.5, SD = 5.5) than the controls (12.6, SD = 12.6), neither of these differences were found to be statistically reliable ($p < .05$).

Comparison of each synaesthete to their matched control group: The performance of each individual synaesthete was compared to their associated group of matched controls in order to explore the effect of colour on performance in more detail. Mean RTs for trials with correct responses for each condition were calculated for each synaesthete and each group of controls, as shown in Table 3.6.

Table 3.6: Mean response times (RTs) in Task 2 of Experiment 2, as a function of colour condition (congruent, incongruent and no colour), and timeout frequency for synaesthetes and each synaesthete's corresponding group of matched controls (standard deviations in parentheses).

	Mean RT (ms) and SD for colour conditions			**Mean timeout frequency**	**Mean Error rate**
	Congruent	**Incongruent**	**No Colour**		
KD	984 (396)	878 (228)	879 (178)	0	8
KD controls	1124 (374)	1134 (338)	1098 (333)	7.7 (13.3)	12.2 (11.5)
DS	1382 (430)	1261 (211)	1146 (305)	9	2
DS controls	1049 (333)	1010 (298)	1059 (354)	6.5 (10.1)	16.2 (20.5)
RW	890 (137)	965 (219)	889 (164)	5	12
RW controls	1207 (396)	1149 (347)	1195 (371)	8 (7.5)	12.6 (7.3)
VE	932 (168)	943 (154)	958 (171)	0	0
VE controls	1187 (401)	1168 (378)	1124 (337)	9 (7.8)	9.4 (7.4)

As the graphemes in Task 2 were presented in both normal and backwards format, and at three different angles of rotation, the effect of colour on task performance was explored for each synaesthete and their group of matched controls using a 3x2x3 ANOVA, with colour (congruent, incongruent, and 'no colour'), format (normal and backwards) and angle of rotation (120^{o}, 180^{o}, or 240^{o} away from the upright position) as the between-group variables. For KD this revealed a significant main effect of format (F (1,75) = 16.32, $p < .001$, η^2 = .18), while the effect of colour (F (2,75) = 2.42, p = .096, η^2 = .06) and angle (F (2,75) = 1.2, p =.31, η^2 = .03) were not significant. There was a significant interaction between colour and format (F (2,75) = 4.25, p =.02, η^2 = .1), but no significant interaction between colour and angle (F (4,75) = 2.13, p =.09, η^2 = .1), format and angle (F (2,75) = 0.24, p =.79, η^2 = .01), or between colour and format and angle (F (1,75) = 0.63, p =.65, η^2 = .03). The main effect of format was driven by a faster response to graphemes in normal format (813ms) than backwards format (1039ms). However, as shown in Figure 3.5, the interaction between colour and format was evident, with the trials in backwards format being more affected by the colour manipulation, with the congruent condition being the slowest of the three. For KD's control group there was only a main effect of format (F (1,862) = 30.74, p < .001, η^2 = .03) and a main effect of angle (F (1,862) = 26.28, p < .001, η^2 = .06), with a faster response to the trials with graphemes in normal format than backward format, and trials that required a smaller angle of rotation than the larger angle of rotation.

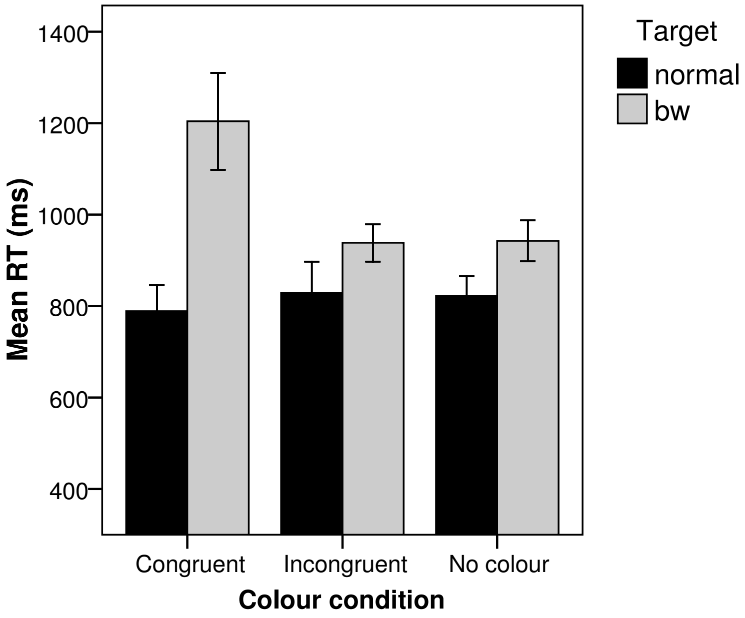


Fig 3.5: Interaction between colour condition (congruent, incongruent and no colour) and grapheme format (normal and backwards) for KD in Task 2 in Experiment 2 (with error bars showing 1 standard error)

For DS this analysis revealed a significant main effect of colour (F (2,72) = 3.74, p =.028, η^2 = .09), and a significant main effect of angle (F (2,72) = 4.87, p =.01, η^2 = .12) while the effect of format approached significance (F (1,72) = 3.7, p = .059, η^2 = .05). None of the interactions were found to be significant. Post-hoc Games-Howell multiple comparisons revealed that the main effect of colour was driven by the slower response to the trials in the congruent condition than the 'no colour' condition (p= .036) and the main effect of angle was driven by a slower response to trials requiring 180° of rotation compared to 240° (p = .013). With the effect of format that was approaching significance, the trials in normal format (1190ms) were responded to more quickly than those in backwards format (1343ms). For DS's control group only the main effects of format (F (1,803) = 18.36, p < .001, η^2 = .02) and angle (F (2,803) = 11.7, p < .001, η^2 = .03) were significant, with a faster response to the trials with graphemes in normal format, and trials that required a smaller angle of rotation.

For RW this analysis revealed a significant main effect of format (F (1,67) = 5.15, p =.027, η^2 = .07), and a significant main effect of angle (F (2,67) = 7.77, p =.001, η^2 = .19) while the effect of colour was not significant (F (2,67) = 2.55, p = .086, η^2 = .07). The interaction between format and angle was significant (F (2,67) = 6.09, p = .004, η^2 = .15), while the remaining interactions were not significant. The main effect of format was driven by a faster response to trials in normal format (865ms) than backwards format (977ms), and post-hoc Games-Howell comparisons showed that the main effect of angle was driven by a slower response to angles requiring 180° of rotation than either 120° or 240° (ps < .01). For RW's control groups only the main effects of format (F (1,834) = 31.67, p < .001, η^2 = .04) and angle (F (2,834) = 25.52, p < .001, η^2 = .06) were significant, with a faster response to the trials with graphemes in normal format than backward format, and trials that required a smaller angle of rotation than the larger angle of rotation.

For VE this analysis revealed a significant main effect of format (F (1,82) = 10.62, p =.002, η^2 = .12), and a significant main effect of angle (F (2,82) = 6.1, p =.003, η^2 = .12), while the effect of colour was not significant (F (2,82) = 0.47, p = .63, η^2 = .01). The interactions between colour and format and colour and angle were not significant, as were the remaining interactions. The main effect of format was driven by a faster response to trials in normal format (900ms) than backwards format (994ms), and post-hoc Games-Howell comparisons showed that the main effect of angle was driven by a slower response to angles requiring 180^o of rotation than either 120^o or 240^o (ps < .05). For VE's control groups only the main effects of format (F (1,875) = 33.57, p < .001, η^2 = .04) and angle (F (2,875) = 36.7, p < .001, η^2 = .08) were significant, with a faster response to the trials with graphemes in normal format than backward format, and trials that required a smaller angle of rotation than the larger angle of rotation.

Table 3.6 also shows the timeout frequencies and error rates for each synaesthete and the mean timeout frequency and mean error rate for their associated group of matched controls. Although most of the synaesthetes have lower timeout frequencies and error rates than their controls, it can be seen that they are all within one standard deviation of each other. Table 3.7 shows the accuracy rates and frequency of timeouts for the individual synaesthetes across the different colour conditions. From this table it can be seen that there is very little difference in the rates across the conditions, and so colour of grapheme does not seem to have an effect on task accuracy in terms of error rates or frequency of timeouts.

Table 3.7: Synaesthete error rates and timeout frequencies for the 3 conditions (congruent, incongruent and no colour) for Task 2 in Experiment 2

	Timeouts				**Error rate**			
	Overall	Congruent	Incongruent	No colour	Overall	Congruent	Incongruent	No colour
KD	0	0	0	0	8	2	3	3
DS	9	2	3	4	2	0	1	1
RW	5	3	0	2	12	3	4	5
VE	0	0	0	0	0	0	0	0

A whole group comparison of timeout frequencies and error rates to VVIQ scores (as shown in Table 3.2) was performed to see whether there was an association between subjective image vividness and the timeouts / number of errors in Task 2. This analysis found that although there was a significant positive correlation between the number of timeouts and the error rate ($r = 0.57$, $p < .001$) these variables were not significantly correlated with the VVIQ score ($p < .05$).

3.4: Experiment 2 Discussion

Experiment 2 has used modified versions of grapheme-based visuo-spatial tasks, to see whether synaesthetes' task performance was affected by an interaction between the colour of a synaesthetic concurrent and the 'real' colour of the stimuli. The principle aim of the study was to see whether mentally rotating a grapheme could be shown to elicit a synaesthetic concurrent. Overall the results suggest that performance on the visuo-spatial task that required some mental transformation of graphemes (Task 1) was affected by grapheme colour for two of the four synaesthetes, although importantly this was found to interact with the format the grapheme was presented in. Performance on the task that required mental rotation of graphemes (Task 2) was found to also be affected by colour for two of the four synaesthetes, and again format of the grapheme was found to interact with colour for one of these synaesthetes. Interestingly, the synaesthete showing a main effect of colour on the mental rotation task did not show an effect of colour on the task using upright graphemes. These results add support to the idea that the cognitive process of mental rotation can elicit a synaesthetic concurrent for some synaesthetes, as the colour effect was only found with the task requiring mental rotation processes. However, it does need to be acknowledged that both tasks involved some visual processing of the graphemes, in addition to the spatial processing. Furthermore, colour effects were again not found for all synaesthetes.

Task 1 was a mirror-image discrimination task, in which some visuo-spatial processing was required to decide whether the visually presented grapheme was in normal or backwards format. Although the task did not involve any mental rotation processes, it has been suggested by previous research that the task does involve some mental transformation of the stimuli (Alivisatos & Petrides, 1997; Hamm, Johnson, & Corballis, 2004). At a group level, manipulating the colour of the presented grapheme so that it was either congruent or incongruent with the synaesthete's concurrent associated with that grapheme showed a reliable effect of colour on task performance. Colour was found to have a significant effect, so that for both synaesthetes and controls the mean incongruent RT was slower than the mean congruent RT. It is not clear why this would be the case for the controls. However, the actual difference between the mean congruent and incongruent RT for the controls as a group was only 21ms. Importantly, there was a reliable difference between the size of the congruency effect for the synaesthetes and the congruency effect for the controls, showing that the difference between the colour conditions was larger for the synaesthetes than the controls. This suggests that the synaesthetes' performance was more affected by colour than the controls' performance. Therefore, as previous synaesthesia research has shown that the interaction between the synaesthetic concurrent and 'real' colour can interfere with the visual processing of stimuli (Smilek, Dixon, Cudahy, & Merikle, 2001) Task 1 has shown that the interaction between the synaesthetic concurrent and 'real' colour of graphemes can interfere with the visuo-spatial processing of upright stimuli. As hypothesised, the synaesthetes were slower when the grapheme was presented in an incongruent colour, which supports the idea that viewing an incongruently coloured grapheme uses attentional resources (Paulsen & Laeng, 2006; Weiss, Zilles, & Fink, 2005), resulting in fewer resources being available for the processing required for this visuo-spatial task.

Importantly however, at an individual level of analysis, the effect of colour was found to reliably affect only two of the four synaesthetes' performance on Task 1, and these effects of colour were found to interact with the format that the grapheme was presented in. Furthermore, the pattern of this interaction differed between the two synaesthetes. It was expected that, regardless of grapheme colour, the backwards trials would be slower than the normal trials for both the synaesthetes and non-synaesthetes (Hamm, Johnson, & Corballis, 2004). This slower response time for the trials with backwards graphemes was expected to be associated with the use of greater attentional processes. Based on this premise, it was predicted that the backward trials would result in a reduced processing capacity for task-irrelevant features, such as colour, and so it was predicted that, for synaesthetes, colour would have less of an effect on the trials with backwards graphemes than trials with normal graphemes. Some support for this idea can be seen with the interaction between colour and grapheme format found with KD's results. With the backwards graphemes colour can be seen to have had very little effect on his task performance, with a similar performance in each of the colour conditions (see Figure 3.3). As expected, with the normal graphemes, there was a clear difference in task performance between the colour conditions. Interestingly however, while he was much faster with the normal graphemes in the congruent condition, potentially suggesting that the congruent colour facilitated his task performance, his slowest performance was with the normal graphemes in the 'no colour' condition (and slower than the backward graphemes in the 'no colour' condition). This therefore suggests that KD's performance on Task 1 with the normal graphemes was in some way hindered when presented in the 'no colour' condition. One possible post-hoc explanation for this could be that when the normal graphemes were presented in the 'no colour' condition (i.e. in black font) the processes involved in eliciting the synaesthetic concurrent hindered his task performance; when the graphemes were presented in the congruent condition these processes were not needed, as the congruent colour was already visually displayed, and so his performance was faster. Overall however, it would seem that for colour to affect KD's task performance, the grapheme needed to visually look like the inducer (i.e. be in normal format), which provides some support for the idea put forward by Hubbard et al (2006), that it is the visual percept of the grapheme that elicits the synaesthetic experience rather than the concept.

In sharp contrast to KD, for VE the effect of colour was found to be much larger with the backward trials than the normal trials, and so in the opposite direction to that predicted. Overall, VE was slower in the backward trials than the normal trials, but she was particularly slowed when the backward graphemes were presented in the incongruent condition (see Figure 3.4). One possible explanation for VE's difference in colour effects between grapheme formats could be her general difference in response times between formats. Potentially, the extra time it took VE to make the decision with the backward trials may have allowed a stronger, or more vivid synaesthetic concurrent to be elicited, resulting in greater interference between the synaesthetic concurrent and the 'real' colour. However, this account seems unlikely given that priming studies have shown that the synaesthetic concurrent elicited from an inducer presented for only 500ms can be shown to affect subsequent task performance (Mattingley, Rich, Yelland, & Bradshaw, 2001). Furthermore, a recent study of the temporal aspects of coloured hearing synaesthesia suggested that the colour processing areas of the brain were activated only 122ms after stimulus onset (Beeli, Esslen, & Jancke, 2008). Therefore, as her average response time for the normal trials was greater than this (701ms), it could be argued that VE would be expected to show the same congruency effect for the normal trials as the backward trials if the amount of time spent looking at the inducer was important.

Another explanation is that when backward graphemes were presented to VE in an incongruent colour, the additional attentional mechanisms used by viewing the incongruently coloured grapheme (Paulsen & Laeng, 2006; Weiss, Zilles, & Fink, 2005) resulted in fewer attentional mechanisms available for the decision. Consequently, this slower response time was not found with the congruent backward graphemes, as the congruent colour did not utilise the same cognitive control mechanisms (and also for the ‘no colour’ condition). This account however does not support Mattingley et al’s (2006) idea that decreasing the attentional resources available with a more demanding task actually reduces the processing of the synaesthetic inducer. Mattingley et al used Lavie’s account (1995) to argue that a task with high perceptual load results in less residual capacity for processing irrelevant aspects of stimuli. In the case of synaesthesia it was suggested that this would be the processing of the stimulus colour, as this was irrelevant to task performance. However, with the current data for VE it appears that with increased perceptual load (i.e. when the graphemes were presented in backward format) there was increased processing of the potentially irrelevant colour.

Overall, the findings from Task 1 therefore further illustrate the importance of the issue of heterogeneity with synaesthetes. Although colour was found to significantly affect task performance for two of the four synaesthetes, the direction of the effect was again found to differ across synaesthetes (as found with Experiment 1). One potential post-hoc explanation for the current difference could be to do with differences in their subjective descriptions of their concurrents, as while VE can be classified as a “projector” synaesthete, whereas KD would be classified as an “associator” synaesthetes. However, it needs to be kept in mind that task strategy has also previously been shown to have an effect on the neural processes used in mental rotation tasks (Kosslyn, Thompson, Wraga, & Alpert, 2001; Wraga, Shephard, Church, Inati, & Kosslyn, 2005), and so although the participants were all given the same instructions, differences in approach to the task may have resulted in the observed difference in congruency effects from the different grapheme formats.

Task 2 was a visuo-spatial task that was very similar to Task 1, but with the additional demand of mental rotation. The same mirror-discrimination task was used, with the same graphemes presented in both normal and backwards formats, but the graphemes were not presented in the upright position. Therefore, in order to decide whether each grapheme was normal or backwards, the participants were instructed to mentally rotate the grapheme to the upright position before making the decision. Importantly, the response times suggest that both the synaesthetes and non-synaesthetes did use mental rotation processes, as the responses were slower for the trials that required a greater angle of rotation, and for the trials with backwards graphemes. It can therefore be argued that the participants were using a spatial imagery process. At a group level the difference in response times between colour conditions was not found to be statistically reliable, for either the synaesthetes or the controls.

However, at an individual level, a significant effect of colour was found for one of the four synaesthetes, and for another synaesthete there was a significant interaction between colour and grapheme format. For the control groups, colour was not found to effect performance on Task 2.

It had been predicted that colour would affect the synaesthetes' performance on the mental rotation task, and that this effect would be smaller for trials that required more rotation, and for trials presented in backwards format (due to the reduction of processing capacity with these trials, as described earlier). Although an interaction between colour and grapheme format was found for KD, this did not provide support for hypothesis. When the graphemes were presented in normal format, there was little difference between KD's performances in the different colour conditions. However, when the graphemes were presented in backwards format there was a more evident difference between the colour conditions; when the backward graphemes were presented in the congruent condition he was much slower than when they were presented in either the incongruent or 'no colour' conditions. This suggests that with the more cognitively demanding trials (i.e. when the graphemes were in backwards format), the congruent condition slowed his performance. This pattern of results is in the opposite direction to the prediction that trials requiring less cognitive processing would result in a greater effect of colour. Additionally, the direction of the colour effect is not as predicted, as it was expected that the incongruent condition would be more of a hindrance than the congruent. Importantly, KD's pattern of results in Task 2 was also very different to his interaction between colour and grapheme format found with Task 1; whereas in Task 1 the colour effect was more evident with the normal graphemes, with Task 2 it was more evident with the backwards graphemes. Furthermore, in Task 1 the congruent condition had been the faster of the colour conditions, and in Task 2 it was the slower. This suggests that the additional mental rotation requirement found with Task 2 resulted in the concurrent having a different impact on KD's task performance.

The other synaesthete to show an effect of colour with Task 2 was DS, and he was also found to be slowest in the congruent condition. The colour effect shown by DS however, was not found to interact with grapheme format. Seemingly, when the grapheme was presented in a colour that matched the colour of the concurrent usually experienced with that grapheme, DS was slower at the mental rotation task than when it was presented in the 'no colour' condition. As with KD, this pattern of results goes against the prediction that the incongruent condition would be more of a hindrance than the congruent condition. This therefore does not support the view that the increased cognitive control mechanisms thought to be activated when a synaesthete is visually presented with an incongruently coloured grapheme (Paulsen & Laeng, 2006; Weiss, Zilles, & Fink, 2005) would result in a slower performance on a mental rotation task. This suggests that either these cognitive control mechanisms were not activated when KD and DS were presented with the graphemic-stimuli in Task 2, or that if they were activated they did not have the anticipated impact on task performance. One possible post-hoc explanation for the slower performance in the congruent condition for these synaesthetes, is that offered by Yaro and Ward (2007), which is that the congruent colour can be found to distracting due to the synaesthetes paying extra attention to this condition (as described in Section 2.4).

In addition to considering the results of individual synaesthetes on the two tasks used in Experiment 2, it is also important to consider these results in comparison to the synaesthetes' performances in Experiment 1. The mental imagery task used in Experiment 1 was conducted in order to see whether it was possible to provide support for the idea that a synaesthetic concurrent could be elicited through object imagery processes. The mental rotation task (Task 2) used in Experiment 2 was conducted in order to see whether it was possible to provide support for the idea that a synaesthetic concurrent could be elicited through spatial imagery processes. It is interesting to note that of the two synaesthetes showing some effect of colour in the mental rotation task used in Experiment 2, one (KD) had not previously shown an effect of colour in Experiment 1, and the other (DS), had shown an effect of colour in Experiment 1, but the colour effect was shown to have a very different impact on his task performance. Furthermore, the two synaesthetes showing no effect of colour in Experiment 2, had both shown a strong effect of colour in Experiment 1.

This suggests a possible difference between the role object and spatial imagery processes may play in the generation of a synaesthetic concurrent. It also further highlights important individual differences. From the results of Experiment 1 and 2, it could be speculated that for some synaesthetes there could be a dissociation between the role different imagery processes may perform in the generation of a concurrent. For example, while both VE and RW were affected by colour in the task using object imagery processes, they were not affected by colour in the task using spatial imagery processes. In contrast, KD was affected by colour with the spatial imagery processes, but not with the object imagery processes. It could also be speculated that for other synaesthetes there may be a difference in the impact of colour on task performance from concurrents generated from either type of imagery process. This has been illustrated with DS, who was slower in the incongruent condition in the task using object imagery processes (Experiment 1), but was slower in the congruent condition in the task using spatial imagery processes (Experiment 2).

Summary of Experiment 2

As found with Experiment 1, Experiment 2 has shown the heterogeneity of the synaesthete population. The findings from Experiment 2 suggest that some synaesthetes' performance on a mirror-image discrimination task using upright graphemes can be affected by the interaction between the 'real' colour of the presented grapheme, and the synaesthetic concurrent elicited by that grapheme. However, the format of the grapheme was found to interact with the effect of colour, and while for one synaesthete the colour effect was found for graphemes presented in normal format, for another it was found for graphemes presented in backwards format. With the task involving mental rotation of the graphemes there was some evidence to suggest that a synaesthetic concurrent can be elicited through spatial imagery processes for some synaesthetes. Grapheme format was again found to be important for one of the synaesthetes, but whereas with the upright graphemes the colour effect had been found with the normal graphemes, with the mental rotation task the colour effect was found with the backwards graphemes. Furthermore, the synaesthetes' performances in Experiment 2 were not found to be consistent with their earlier performances in Experiment 1; some synaesthetes were affected by colour in one of the experiments but not the other, and the synaesthete who did show a colour effect in both experiments was found to be affected by colour in different ways across the experiments. As outlined in the Introduction, there are purportedly important differences between the imagery processes used in Experiment 1 and Experiment 2, with Experiment 1's task using object imagery processes and Experiment 2's task using spatial imagery processes. It could therefore be speculated from Experiment 1 and Experiment 2's results that, for individual synaesthetes, purportedly distinct imagery processes may play different determining roles in the generation of a synaesthetic concurrent from an internally generated mental image of a grapheme. However, it is important to note that aside from the differences in imagery task, there were two further differences between these experiments which may have affected the results. The first relates to the amount of colour visually presented on the screen and the second to the choice of incongruent colours. In order to be more confident that the apparent lack of a colour effect from the spatial imagery process used in Experiment 2 was not due to these design differences, these are explored further in Experiment 3.

Chapter 4 – A further exploration of the role of spatial imagery processes in the generation of a synaesthetic concurrent from a mental image of a grapheme (Experiment 3)

4.1: Experiment 3 Introduction

Experiment 2 explored the effect colour manipulation had on a spatial imagery process; i.e. mental rotation. Mental rotation is a well studied mental imagery process, and many studies have suggested that mental rotation is analogous with rotating an object in physical space. Experiment 2 therefore aimed to see whether manipulation of a grapheme's visual colour had an effect on a synaesthete's ability to mentally rotate it, with the idea that a potential synaesthetic concurrent elicited from the grapheme during the rotation task would interact with the 'real' colour of the grapheme, resulting in the interference in task performance. Participants completed two mirror-image discrimination tasks; one with upright graphemes and the other with graphemes that were rotated away from the upright position. The second task therefore required the graphemes to be mentally rotated to the upright position before making the decision. The colours of the graphemes were manipulated so that they were either congruent or incongruent with the individual synaesthete's concurrent for that grapheme. Overall, the results showed that while the colour manipulation affected task performance on both tasks, and grapheme format was found to interact with the effect of colour, the synaesthetes' performances were not consistent with their earlier performances in Experiment 1. These inconsistencies could therefore be used to speculate about possible differences in the role these purportedly distinct imagery processes may play in the generation of a concurrent from an internally generated mental image of a grapheme.

These differences in individual synaesthete's colour effects across the two experiments can be explained in a number of possible ways. Firstly, it could be due to the neural processes involved in the two tasks. Mental rotation, as used in Experiment 2, has been shown to make use of different neural pathways to other imagery processes (Cohen et al.,, 1996). It is thought to make use of spatial representations rather than visual representations, and it has been suggested that these spatial representations are processed in topographically organised areas of the parietal cortex (Sereno, Pitzalis, & Martinez, 2001). The difference in colour effects found with Experiments 1 and 2 can therefore be used to suggest that activation of object imagery processes, and potentially the early visual areas, could be an important determining factor in production of a synaesthetic concurrent from a mental image for some synaesthetes, whereas for others it could be the spatial processes. Additionally, the rotated graphemes may not elicit synaesthetic concurrents in the same way as upright graphemes. In Experiment 2 the synaesthetes began each trial with a rotated grapheme and so the initial grapheme recognition processes that ostensibly trigger the synaesthetic concurrents may not have been initiated. A recent study using the visual search paradigm found that when searching for targets amongst distractors that were inverted 'L's and 'T's synaesthetes did not show the usual colour effect (Sagiv, Heer, & Robertson, 2006). Furthermore, the mental rotation process used in Experiment 2 may have inhibited the verbal/lexical processing of the graphemes, as previous studies with non-synaesthetes has shown that mentally rotating graphemes does not activate the usual verbal/lexical pathways (Jordan, Heinze, Lutz, Kanowski, & Jancke, 2001).

However, before these explanations for the differences in colour effects between the experiments can be considered in any depth, crucial methodological differences between Experiment 1 and 2 also need to be considered. Aside from the differences in mental imagery process, there were two further differences between these experiments which may have affected the results; i) the amount of colour visually presented on the screen and ii) the choice of incongruent colours. With regards to the amount of colour presented, in Experiment 1 the image was created against a computer screen that was filled with colour. In contrast, in Experiment 2, although the individual graphemes differed in colour, the vast majority of the computer screen remained white. There was therefore a clear difference in the amount of colour visually presented between the two studies. The second difference between the studies relates to the choice of incongruent colours. Experiment 1 used four graphemes; the congruent colours were the colours that matched the concurrent elicited for each grapheme and the incongruent colours were the colours that matched each of the other three graphemes. For example, if the graphemes ‘E’, ‘F’, ‘L’ and ‘P’ were used, then the incongruent colours for ‘E’ were the colours used for ‘F’, ‘L’ and ‘P’. Therefore, in Experiment 1 only four different colours were used, the incongruent colours all came from the synaesthete’s own “colour alphabet” (i.e. the colours of the concurrents elicited by each grapheme for an individual synaesthete), and there was an incongruent to congruent colour ratio of 3:1. However, in Experiment 2 six graphemes were used (to be in line with Alivisatos & Petrides, 1997), and again while the congruent colour matched the synaesthetic concurrent elicited by that grapheme, the incongruent colour for each grapheme was a colour that another synaesthete associated with that grapheme. For example, if the congruent colour for ‘2’ for one synaesthete was blue, then the incongruent colour selected for that synaesthete was the colour another synaesthete experienced for ‘2’, such as yellow. This meant that for each synaesthete in Experiment 2, there were twelve different colours, the incongruent colours did not come from each synaesthetes’ individual “colour alphabet”, and there was an incongruent to congruent ratio of 1:1.

Previous studies measuring the impact the conflict between the synaesthetic concurrent and ‘real’ colour has on task performance have mostly used an incongruent colour selected from within the synaesthete’s own colour alphabet (for example, Hubbard, Arman, Ramachandran, & Boynton, 2005). It is not clear whether the difference in colour effects found between Experiment 1 and Experiment 2 could be due to the method of selection of incongruent colours. However, since a suggested explanation of the congruency effect found with Experiment 1 related to the bi-directionality of synaesthesia (i.e. seeing a colour associated with a particular grapheme made it more difficult to visualise a grapheme not associated with that colour) it is important to further explore this possibility. Furthermore, synaesthetes are probably accustomed to seeing graphemes presented in the ‘wrong’ colours as this must frequently occur in everyday life. In contrast, seeing a grapheme presented in a colour that they associate with another grapheme must be very unusual, especially as the colours of synaesthetes’ alphabets are often not prototypical colours. This may have resulted in the difference in congruency effects with the mental rotation task, as it could be that using incongruent colours that are not from the synaesthetes' own "colour alphabet" is unlikely to result in a reliable congruency effect for some synaesthetes, or may have a bearing on the direction of the colour effect. The ratio of incongruent to congruent colours may also have reduced the difference between colour conditions, as having an equal proportion of congruent and incongruent trials may have allowed some synaesthetes to become accustomed to viewing the incongruently coloured graphemes. For example, due to pilot data with non-synaesthetes showing only weak interference with an equal number of congruent and incongruent trials, Elias et al (2003) used a 3:1 incongruent to congruent ratio, as was also used in Experiment 1.

Aims and Rationale of Experiment 3

Experiment 3 was therefore designed as a result of the questions raised by the findings of Experiment 1 and 2. It aimed to replicate the mental rotation task from Experiment 2, but with a modified design so that its colour manipulation was more analogous with the method used in Experiment 1. Consequently, in Experiment 3 participants were required to mentally rotate achromatic stimuli that were placed on coloured backgrounds, and the background was coloured either congruently or incongruently with the grapheme for that individual. The incongruent colours were made up of colours from within the individual synaesthete's "colour alphabet". For example, if letters "F" and "G" were used then the incongruent colour for "F" would be the congruent colour for "G" and so on. Additionally, an incongruent to congruent trial ratio of 2:1 was used whereas in Chapter 3 it has been a 1:1 ratio (a 2:1 ratio was selected rather than 3:1 in order to keep the total number of trials to a minimum to reduce any effects of participant fatigue). As the focus of the study was the potential synaesthetic concurrent elicited from the imagery process of mental rotation, only one task was used in Experiment 3, which combined upright graphemes with graphemes that required rotation.

4.2: Experiment 3 Method

Participants

The four grapheme-colour synaesthetes (KD, DS, RW and VE) that completed both Experiments 1 and 2 took part in the current study. Their details are presented in Chapter 3 (see Table 3.2). Control participants were not recruited for the current study.

Materials

The mental rotation task was run on a PC using the software E-Prime. A separate set of stimuli was created for each synaesthete so that the congruent and incongruent colours were as close as possible to the colours of the concurrents elicited by each of the graphemes (this was based on colour information provided in pre-test assessment, as used in Experiments 1 and 2).

In the mental rotation task the target stimuli for all synaesthetes were two asymmetrical uppercase letters (‘F’ and ‘G’) and two asymmetrical digits (‘5’ and ‘7’), presented in both their ‘normal’ format and ‘backwards’ format (a mirror version of the normal). These graphemes were selected as the colours associated with them by each of the synaesthetes was suitable for the testing procedure (i.e. each had distinct colours that were visible on the computer monitor). Only four graphemes were used in order to keep the numbers of trials to a minimum. All of the stimuli were grey in colour and were presented in one of four positions; upright, 120^0 or 180^0 or 240^0 away from upright. Each grapheme was presented in the centre of the computer screen within a grey outline of a circle. The screen was either white (for baseline trials) or filled with colour. When coloured, the screen was either congruent or incongruent for the grapheme being presented in that trial. There was a 2:1 incongruency to congruency ratio, and the incongruent colours used were two colours from the other graphemes used for that synaesthete. The two incongruent colours chosen from the possible three were the ones least similar (through visual comparison) to the congruent colour.

Procedure

After giving written consent and completing six practice trials, the synaesthetes completed the main mental rotation task. Participants were told that they would see a series of letters and numbers presented one at a time in the centre of the computer screen, and that their task was to decide whether the grapheme was ‘normal’ or ‘backwards’, responding as quickly as possible without sacrificing accuracy (see Appendix C). They were told that some of the graphemes would be upright and some would not. For those that were not upright, participants were told that they would need to mentally rotate the grapheme to the upright position to work out their response. For each trial participants saw a small black fixation cross in the centre of a white screen for 1500ms, and this was followed automatically by the target stimuli. The target stimuli remained on the screen until the response was given or for a maximum of 2500ms. Participants gave a spoken response into a microphone, and the response-latency was recorded by the PC. The spoken response was also hand recorded for later accuracy analysis. Trials in which no response was given within the 2500ms were recorded as ‘timeouts’. In total there were four stimuli (‘F’, ‘G’, ‘5’, ‘7’) with four possible coloured backgrounds (1x congruent, 2x incongruent, 1x baseline), two grapheme formats (‘normal’ or ‘backwards’) and four angles of rotation (upright, 120^0 or 180^0 or 240^0 away from upright) resulting in 128 possible trials. Each trial was presented once in a random order.

4.3: Experiment 3 Results

For trials with the correct response in the time permitted, outliers were removed (with stem and leaf procedures using SPSS version 15), resulting in between 6% and 9% of trials being removed per synaesthete (mean = 7.25%). Subsequently, the mean response time for each synaesthete for each colour condition was calculated for trials with a correct response (within the permitted 2500ms), and this is shown in Table 4.1.

Table 4.1: Mean response times (RTs) as a function of colour condition (congruent, incongruent and no colour) in Experiment 3, with Timeout Frequency and Error Rates (standard deviations in parentheses).

	Mean RT (ms) and SD in colour condition			**Timeout frequency**	**Error rate**
	Congruent	**Incongruent**	**No Colour**		
KD	785 (187)	786 (165)	795 (187)	0	13
DS	1020 (360)	1026 (207)	1030 (303)	1	2
RW	1065 (323)	985 (232)	1049 (305)	4	10
VE	861 (134)	845 (146)	898 (193)	0	1

The effect of colour on each synaesthete's task performance was explored with individual 3x2x4 ANOVAs, with colour (congruent, incongruent, and 'no colour'), format (normal and backwards) and angle of rotation (0^0, 120^0, 180^0 and 240^0) as between group variables. For KD this revealed that the effects of colour ($F(2,81) = 0.15$, $p = .86$, $\eta^2 = .004$), grapheme format ($F(1,81) = 0.15$, $p = .7$, $\eta^2 = .002$), and angle ($F(3,81) = 2.2$, $p = .09$, $\eta^2 = .08$) were not significant, and neither were the interactions between colour and format ($F(2,81) = 1.9$, $p = .16$, $\eta^2 = .05$), colour and angle ($F(6,81) = 1.03$, $p = .41$, $\eta^2 = .07$) and colour and format and angle ($F(6,81) = 0.93$, $p = .48$, $\eta^2 = .07$).

For DS there was no effect of colour ($F(2,93) = 0.01$, $p = .995$, $\eta^2 < .001$), a significant effect of grapheme format ($F(1,93) = 11.8$, $p < .001$, $\eta^2 = .11$), and angle of rotation ($F(3,93) = 5.7$, $p < .001$, $\eta^2 = .16$), but again the interactions between colour and format ($F(2,93) = 0.1$, $p = .9$, $\eta^2 = .002$) and colour and angle ($F(6,93) = 1.55$, $p = .17$, $\eta^2 = .09$) were not significant. The main effect of format was driven by a faster response to trials in normal format (940ms, SD = 249) than backwards format (1112ms, SD = 275), while Games-Howell post-hoc comparisons showed that the graphemes requiring 180° of rotation were significantly slower than all other angles (ps < .05).

For RW, although the effect of colour was not significant (F(2,81) = 1.04, p = .36, $\eta^2 = .03$), there was a significant effect of grapheme format (F(1,81) = 12.5, p = .001, $\eta^2 = .13$), and angle (F(3,81) = 6.3, p = .001, $\eta^2 = .19$). Plus there was a significant interaction between colour and grapheme format (F(2,81) = 3.18, p = .047, $\eta^2 = .07$), while the interaction between colour and angle was not significant (F(6,81) = 0.48, p = .82, $\eta^2 = .03$). Her main effect of format was driven by a faster response to trials in normal format (940ms, SD = 274) than backwards format (1118ms, SD = 253), while Games-Howell post-hoc comparisons showed that the graphemes requiring 180° of rotation were significantly slower than all other angles (ps < .05). However, the interaction between colour and grapheme format is illustrated in Figure 4.1, and it can be seen that when the graphemes were backwards she was much slower in the congruent condition, whereas when the graphemes were presented in normal format she was fastest in the congruent condition.

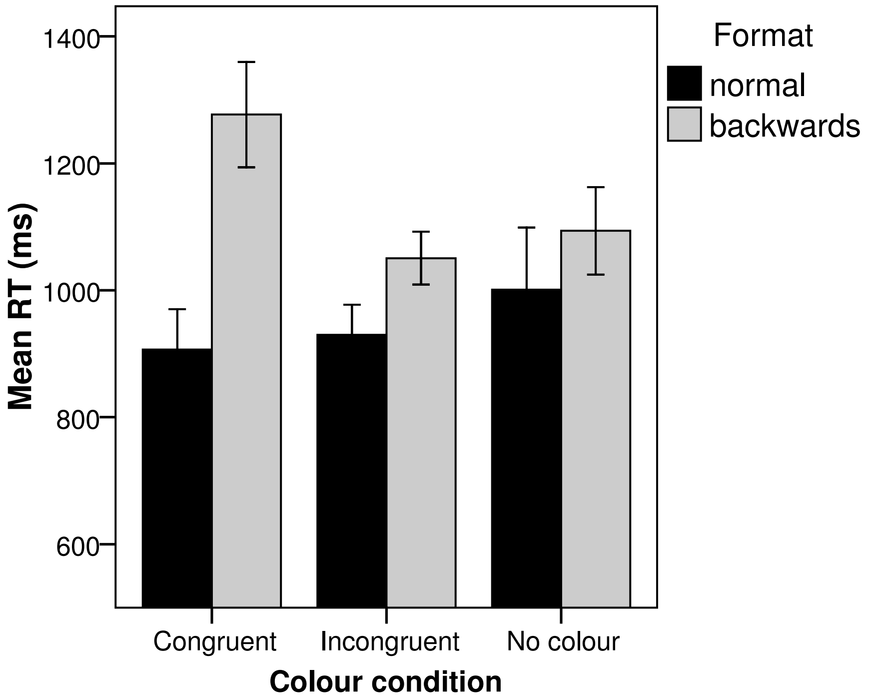


Fig 4.1: Interaction between colour condition (congruent, incongruent and no colour) and grapheme format (normal and backwards) for RW in Experiment 3 (with error bars showing 1 standard error)

For VE the effect of colour was not significant (F(2,95) = 2.32, p = .1, η^2 = .05), but there were significant effects of grapheme format (F(1,95) = 6.4, p = .01, η^2 = .06), and angle of rotation (F(3,95) = 9.58, p < .001, η^2 = .23). The interaction between colour and grapheme format was not significant (F(2,95) = 0.18, p = .84, η^2 = .004) but there was a significant interaction between colour and angle of rotation (F(6,95) = 2.18, p = .05, η^2 = .12). Her main effect of format was driven by a faster response to trials in normal format (825ms, SD = 149) than backwards format (901ms, SD = 156), while Games-Howell post-hoc comparisons showed that the graphemes requiring 180° of rotation were significantly slower than the upright graphemes (p < .001). The interaction between colour and grapheme format is illustrated in Figure 4.2, and it can be seen that she was much slower when the grapheme required 180^0 of rotation and there was no background colour, when compared to the other colour and angle conditions.

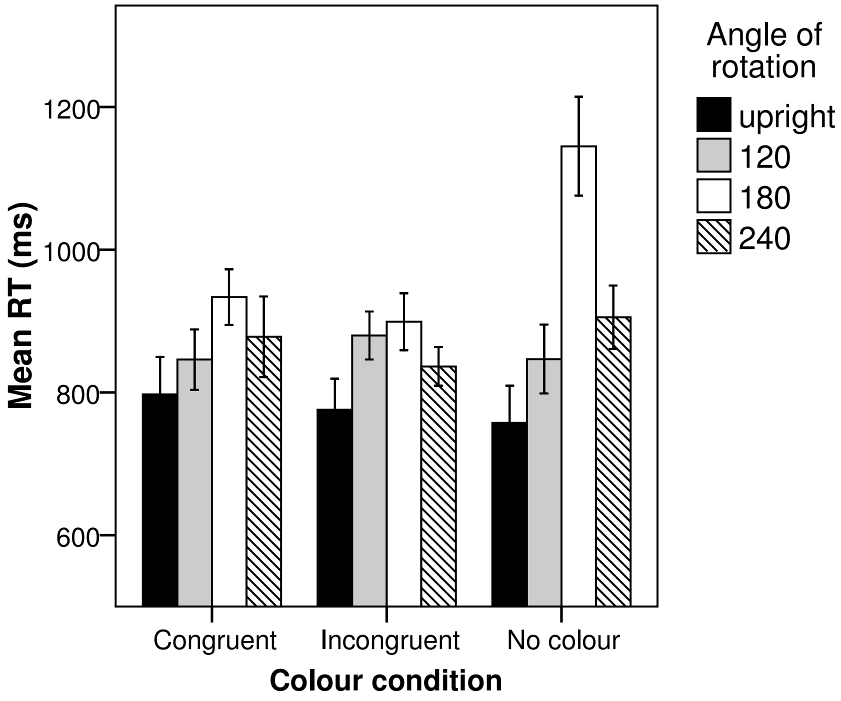


Fig 4.2: Interaction between colour condition (congruent, incongruent and no colour) and angle of rotation (‘0^0’, ‘120^0’, ‘180^0’ and ‘240^0’) for VE in Experiment 3 (with error bars showing 1 standard error)

Table 4.1 also shows the error rates and timeout frequencies for the four synaesthetes. It can be seen that the timeout frequencies are low for all four synaesthetes, while two of the synaesthetes have slightly larger error rates (KD and RW). For KD the error percentages for each condition were 13% of congruent, 11% of incongruent and 6% of ‘no colour’ trials. For RW the error percentages for each condition were 3% of congruent, 11% of incongruent and 6% of ‘no colour’ trials. A significant association between accuracy and colour conditions was not found for these synaesthetes ($p < .05$).

Comparison of congruency effects in imagery tasks in Experiments 1, 2 and 3: In order to compare the effect of colour on task performance in the imagery tasks in Experiment 1, Experiment 2 (Task 2) and Experiment 3, a modified congruency effect was calculated (mean congruent RT – mean incongruent RT / mean no colour RT) for each of the synaesthetes that took part in all three experiments. For Experiments 2 and 3 this involved averaging across the different format conditions and angles of rotation, and for Experiment 3, trials in which the grapheme was presented in the upright position were excluded from this analysis in order to allow a comparison of trials requiring mental rotation between Experiments 2 and 3. Using a modified CE allowed the removal of any differences in general speed of response, and makes performance across the tasks and from synaesthete to synaesthete more comparable. The ‘modified CE’ for each study is shown in Figure 4.3.

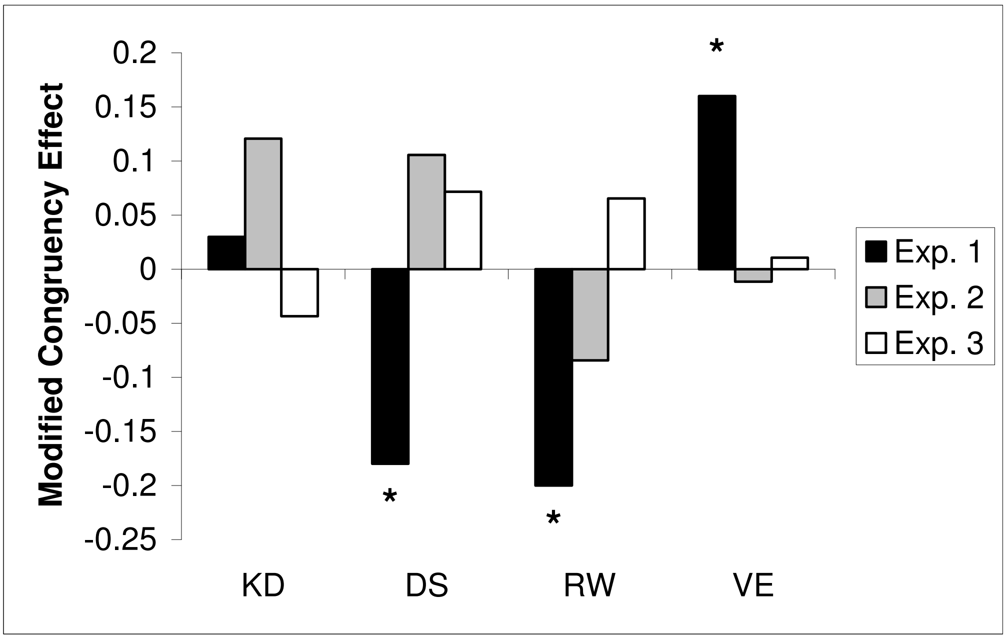


Fig 4.3: Modified congruency effect for each synaesthete in imagery tasks presented in Experiments 1, 2 and 3 (note * = p < .05 for standard congruency effect)

This comparison of colour effects across the experiments clearly illustrates how the CE for VE was very similar across both mental rotation tasks (Experiments 2 and 3), whereas for KD and RW the direction of the CE changed across these tasks. In Experiment 2's mental rotation task KD had been slower in the congruent trials than the incongruent trials (showing a positive CE), whereas in Experiment 3 he was slower in the incongruent trials (showing a negative CE), and vice versa for RW. It also shows that for all but VE the synaesthetes' performance on the mental rotation task was more affected by colour in Experiment 2 than it was in Experiment 3. Furthermore, when comparing the effect of colour in the object imagery task in Experiment 1 to the mental rotation tasks in Experiments 2 and 3, it can be seen that while VE showed a large effect of colour with the object imagery task, her performance on the mental rotation tasks was not affected by colour (as shown by the difference in magnitude of CE). Conversely, KD showed little effect of colour in the object imagery task but showed a much more evident effect of colour in the mental rotation tasks.

4.4: Experiment 3 Discussion

Experiment 3 used a modified version of the mental rotation task used in Experiment 2. It aimed to see whether synaesthetes' ability to mentally rotate a grapheme would be affected by colour manipulation, as found for some synaesthetes with the previous study. However, important changes were made to the colour manipulation used in Experiment 3 because it was not clear whether the discrepancy between the findings of Experiment 1 and Experiment 2 was due the purportedly distinct mental imagery processes, or differences in the colour manipulation method used. In order to make the colour manipulation method more analogous with that used in Experiment 1, the background colour that the grapheme was mentally rotated against was manipulated, rather than the visual colour of the grapheme. Additionally, in contrast to Experiment 2, Experiment 3 compared task performance when the colour matched the concurrent potentially elicited by the rotated grapheme to performance when the colour matched a concurrent elicited by a different grapheme for that synaesthete. Also, to prevent synaesthetes from becoming accustomed to one particular incongruent colour, two different incongruent colours were used with the current study, compared to just the one in Experiment 2. Overall, the findings from Experiment 3 again show that colour had an effect on task performance for two of the four synaesthetes, and once more the effect of colour was found to interact with the presentation of the grapheme (either grapheme format or the angle of rotation required). However, the two synaesthetes who showed this effect of colour had not previously shown a colour effect in the mental rotation task in Experiment 2, and the two synaesthetes who had previously shown a colour effect with the mental rotation task did not show an effect with Experiment 3. This difference in the colour effects found between Experiments 2 and 3 suggests that the changes to the colour manipulation may have impinged on the way the background colour affected task performance. Consequently, whether a concurrent can be measured from a spatial imagery process, for an individual synaesthete, may be dependent upon the colour manipulation method employed.

Importantly, as with Experiment 2, the data suggest that mental rotation was used because as the angle of rotation required increased, so did the synaesthetes' response time, and trials with backward graphemes took longer than trials with normal graphemes. It would therefore seem that the task did require the use of a spatial imagery process. It had been predicted that a greater effect of colour would be found for trials that required less cognitive effort, meaning those that were in normal format and those requiring smaller amounts of rotation (see Table 3.1). However, as with the results of Experiment 2, Experiment 3's results cannot provide support for this hypothesis. VE's performance on the mental rotation task was found to be affected by an interaction between colour and angle of rotation, so that when the angle of rotation required was 180^o, and so more cognitive effort was required, there was a bigger difference between the colour conditions. Similarly, RW's performance was found to be affected by an interaction between colour and grapheme format, so that when the graphemes were presented in backwards format, and so required more cognitive effort, there was a more pronounced effect of colour. When taken together with the results from Experiment 2, these results therefore add further support to the idea that the effect of colour on a synaesthete's performance on a visuo-spatial task is likely to be more evident when the task is more cognitively demanding. As mentioned in Chapter 3, although these results suggest that attentional processes can have an effect on the subsequent concurrent generation, support is not provided for Mattingley et al's (2006) idea that increased attentional demands would attenuate the effect of the concurrent on task performance. It would seem that if the increased attentional demands direct the synaesthete's attention towards the grapheme, as with the mental rotation tasks, then the effect of colour on task performance can be increased.

Interestingly, also as found with Experiment 2, the direction of the colour effects found with Experiment 3 did not support the original hypothesis. It was predicted that the incongruent condition would hinder performance on the mental rotation task (see Section 3.1). However, this was not the case with either VE or RW. VE was found to be most affected by colour when the grapheme needed to be rotated by 180^{o}, and it was in the ‘no colour’ condition. In other words, VE was particularly slowed at the more cognitively demanding trials when the background was white, rather than when it was either congruently or incongruently coloured. This effect of colour is therefore similar to that found with KD in Task 1 of Experiment 2. A possible explanation suggested was that when there is no colour, the synaesthetes spontaneously generate a synaesthetic concurrent, whereas in the congruent condition this is not required to the same extent, as the colour is visually displayed. The slower response in the ‘no colour’ condition would therefore be as a result of the process of generating the concurrent distracting in some way from the task completion. However, in contrast to VE, RW was found to be particularly effected by the background colour with the backwards graphemes when it was congruent with the synaesthetic concurrent, again highlighting the heterogeneous nature of the synaesthete population. This was similar to the pattern of results found with KD and DS with the mental rotation task in Experiment 2, and so the same explanation relating to the congruent condition acting as a distractor can be offered. However, as the entire background was coloured to match the concurrent with the current task, rather than just the grapheme, it could also be suggested that RW found the task more difficult with the congruent condition because the concurrent generated during the mental imagery process made it more difficult to distinguish the grapheme from the background (like the camouflage effect suggested by Smilek et al., 2001). Interestingly, however, RW's pattern of results in Experiment 3 was very different to the effect of colour she showed with Experiment 1, in which she was found to be fastest in the congruent condition. Like the comparison of DS's performance in Experiment 1 and 2, by comparing the effect of colour on RW's performance in Experiment 1 and 3, it is possible to speculate that the distinct imagery processes thought to be used in each task may play different roles in determining the direction of the type of effect colour would have.

The main difference between the findings of Experiment 2 and 3 concerns the identity of the synaesthetes who were shown to be affected by the colour condition. Whereas in Experiment 2 KD and DS were shown to be affected by the colour of the grapheme in the mental rotation task, in Experiment 3 the coloured backgrounds was found to have very little effect on their task performance. In contrast the two synaesthetes who were shown to be affected by the background colour in Experiment 3, RW and VE, had not been affected by the colour of the graphemes with the mental rotation task in Experiment 1. As the main difference between these studies relates to the colour manipulation method, this difference between the experiments suggests that for some synaesthetes the actual form of the colour manipulation may be important in measuring the generation of a synaesthetic concurrent. A non-significant effect of colour does not in itself show that concurrents were not elicited during the task, but rather it shows that there was no reliable effect of the colour manipulation method used. It is therefore important to consider the differences between these Experiments to see why a reliable effect of colour was observed with each particular form of colour manipulation. For example, with regards to RW and VE, manipulating the visual colour of the grapheme did not significantly affect their task performance, whereas manipulating the background colour that the grapheme was mentally rotated against did. The main differences were the amount and location of the visually presented colour, the method used for selecting incongruent colours, and also the ratio of congruent to incongruent colours. As the results from Experiment 3 for RW and VE do not appear to relate to the incongruent condition, it can be argued that it was more likely to be the location and amount of visually presented colour that was behind the difference in results. Similarly, for KD and DS, the pattern of results for the significant colour effect in Experiment 2 did not relate to the incongruent condition, and so it would seem that the location or amount of visually presented colour was important. This therefore suggests that the method of colour manipulation used may have important implications for measuring the effect of a synaesthetic concurrent on task performance.

Summary of Experiment 3

The findings of Experiment 3, in addition to those from Experiment 2, suggest that spatial imagery processes, as required with a mental rotation task, can result in a measurable synaesthetic concurrent for some synaesthetes. However, in general the format of the grapheme has been found to be important, with the colour effect being more evident with more cognitively demanding mental rotation trials. The results from all of the experiments presented so far provide support for the idea that there are important individual differences between the synaesthetes. In particular, from the results of the current study it is apparent that these can be further compounded by the spatial location and/or amount of visually presented colour used within the experimental procedure, as this can also be shown to play a determining role in the observation of a concurrent. The focus for the current thesis is the determinants of a synaesthetic concurrent from an internally generated mental image of a grapheme, and from the results so far it would seem that a concurrent can potentially be measured from both object and spatial imagery processes, but the specific form of imagery may influence the subsequent effect the concurrent has on task performance (as shown by both DS and RW with their contrasting colour effects with the object imagery and spatial imagery tasks). Consequently, as it appears from the studies presented so far that the imagery process itself could be an important determinant, the impact of these purportedly different imagery processes will be explored further in the subsequent experiments.

Chapter 5: Exploring the determinants of a synaesthetic concurrent from different mental imagery processes (Experiment 4)

5.1: Experiment 4 Introduction

The experiments presented so far suggest that purportedly distinct imagery processes may play an important determining role in the generation of a synaesthetic concurrent from a mental image. However, although the tasks used in the earlier experiments made use of either an object or spatial imagery process, the tasks themselves were not entirely comparable. Important differences include the task procedure and requirements for successful completion of the task. For example, while image generation was required for the object imagery task, it was not required for the spatial imagery task in which the graphemes were visually presented. A comparison of response times across the tasks also reveals a difference in cognitive effort required, as trials in the object imagery task took much longer to complete than those in the spatial imagery tasks. This is especially important considering the finding that the more demanding spatial imagery trials in Experiments 2 and 3 showed a greater effect of colour. Consequently, it is not yet possible to conclude that any apparent difference in concurrent generation was due to the imagery processes per se. Accordingly, in order to explore the determinants of a synaesthetic concurrent from a mental image it is important to systematically consider the potentially different mental imagery processes.

Previous explorations of imagery processes have attempted to explain what is meant by a distinct mental imagery process. It has been suggested that imagery tasks can be designed to incorporate two general levels of processes (Kosslyn, 1994; Kosslyn & Plomin, 2001). The first is a 'minimally sufficient' process, which is one that the individual performing the task needs to be able to do, but being better or worse at the process would not affect overall task performance. In contrast, the second is a 'rate-limiting' process which contributes the most towards the dependent variable, as an individual's ability to perform a rate-limiting process would be expected to affect task performance. Kosslyn (1994) points out that when performing an imagery task there can be many different processes involved, as individuals may take different approaches to the same task. However, imagery tasks can be designed so that using an anticipated class of strategy is advantageous for faster task completion. For example, Kosslyn et al (1984) created a set of imagery tasks that were thought to utilise differing underlying processes and importantly found that an individual's performance on the tasks was not strongly correlated, suggesting that an individual could be good at one mental imagery process, but not necessarily another. Wallace and Hofelich (1992) looked at practice effects in imagery ability, finding that prior practice on a task using a particular imagery process led to improved performance on another task that purportedly used the same imagery process, but not on one using a different imagery process. Additionally a study looking at whether ambiguous figures in mental images can be reinterpreted (Mast & Kosslyn, 2002) found that of the four mental imagery abilities identified and assessed in a visual cognition test battery, only the "image transformation" process was strongly associated with image reversal ability, showing how certain imagery tasks require strengths in specific imagery processes. Based on these, and additional studies (e.g. Kosslyn, Van Kleeck, & Kirby, 1990) it has been proposed that "imagery involves a relatively small number of processing subsystems that are drawn upon in different combinations for different tasks" (Kosslyn, 1994, p. 396). This idea has been further supported by a PET study (Kosslyn et al., 2004) which found that the processes required for a set of tasks using purportedly distinct imagery processes were mostly independent from each other, as variation in rCBF in most brain areas was generally only predicted by performance on one task (although there were a few common areas of activation that were thought to be associated with the shared attentional processes and the spatial representations needed for the task).

Consequently, to explore the determinants of a synaesthetic concurrent from a mental image of a grapheme more systematically, Experiment 4 used a modified version of a Visual Cognition Battery (Kosslyn, Shephard, Burrage, & Thompson, 2006). This battery included four imagery tasks that each required the use of a purportedly different imagery process. Importantly, the tasks were all comparable to each other in terms of stimuli to be visualised (i.e. graphemes) and task procedure, but a critical difference between them was the 'rate-limiting' imagery process. Furthermore, two of the imagery tasks can be seen to utilise object imagery processes and two to utilise spatial imagery processes. The two rate-limiting object imagery processes involved (1) the complexity of the image (Object Task), and (2) the level of detail within the image (Resolution Task). Based on spatial imagery processes, the two remaining tasks involved (3) the image transformation process (Transformation Task) and (4) image scanning the spatial layout of an image (Spatial Task). Experiment 4 therefore provided an opportunity to potentially replicate the findings of the earlier experiments, using tasks that were more comparable to each other, and to add to the findings with the addition of an extra object imagery task, and an extra spatial imagery task. In addition to the four imagery tasks the battery also included a Visual Task that followed the same format and required the same decision as the Object and Resolution Tasks, but with the difference that the graphemes were visually presented in each trial, so imagery was not required for this task. The Visual Task was included to see whether synaesthetes would perform similarly on this task as those imagery tasks thought to utilise the early visual areas (i.e. the Resolution Task).

As before, in order to systematically explore whether a synaesthetic concurrent could be measured from each of these purportedly different imagery processes, the background colour each grapheme was visualised against during the tasks was manipulated to be congruent or incongruent with the synaesthetic colour of the grapheme being visualised. In addition to the conventional incongruent condition (using one of the colours induced by a different grapheme for that synaesthete) there was an “opponent” condition, in which the colours were visually opponent to the relevant congruent colour. As outlined in Chapter 1, the concept of colour opponency comes from the “Dual-Process Theory” of colour perception (Hurvich & Jameson, 1957) which proposed that there are colour opponent receptive fields producing two chromatic ‘channels’ (red-green channel and blue-yellow channel) and one achromatic ‘channel’ (light-dark). Importantly these opponent fields result in it not being possible to process both red and green, or both blue and yellow, as part of the same colour, and so these colours are thought of as visually opponent (Chichilnisky & Wandell, 1999; Zeki, 1980). In relation to synaesthesia research, this opponent condition has been used with the synaesthetic Stroop paradigm to show that synaesthetically induced colour, like real colour, is processed in opponent colour channels (Nikolić, Lichti, & Singer, 2007) providing support for the idea that the synaesthetic concurrent is processed at an early stage of visual processing. Hence an opponent condition was added to the current tasks to see whether there was evidence of this physiological conflict between synaesthetic colours induced from a mental image of a grapheme and the visually perceived background colour. In addition to the coloured conditions there was a ‘no colour’ condition.

Summary of Experiment 4’s tasks and hypotheses:

All of the imagery tasks had a very similar procedure which involved forming mental images of graphemes within a circle on a computer screen, and then making a forced choice decision about each image. As synaesthetes who had previously taken part in the earlier experiments were invited to take part in the current study, it was possible to make predictions about the expected effect of colour on individual synaesthete’s task performance. Essentially, a colour effect was expected in the tasks using object imagery processes for the synaesthetes who had shown an effect of colour in Experiment 1’s imagery task, with the same direction of the effect. A colour effect was also expected in the tasks using spatial imagery processes for the synaesthetes who had shown an effect of colour in either Experiment 2 or Experiment 3’s mental rotation task.

The Object Task was expected to use an object-imagery process, and it required participants to visualise a grapheme within a divided circle on a computer screen, and make a size-based decision (see Figure 5.1). The specific rate-limiting process was the image complexity, as the task required the visualisation of graphemes with more composite parts than used in the other tasks (consisting of four or more composite parts, e.g. W, R etc). Previous mental imagery studies have shown that it takes longer to visualise letters with more 'parts' (Kosslyn, Cave, Provost, & von Gierke, 1988), in the same way as it would take longer to write them. Therefore for the Object Task it was hypothesised that there would be a significant congruency effect for synaesthetes RW, DS, and VE, with the congruent condition being faster than the incongruent condition for RW and DS, and vice versa for VE.

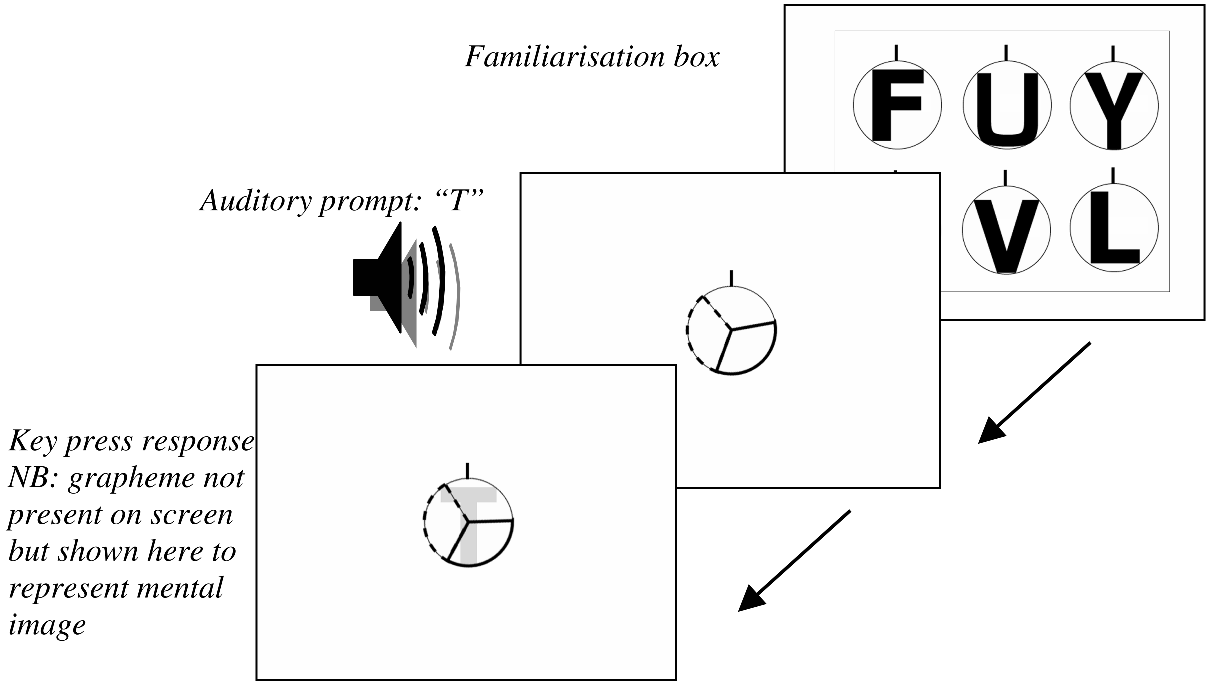
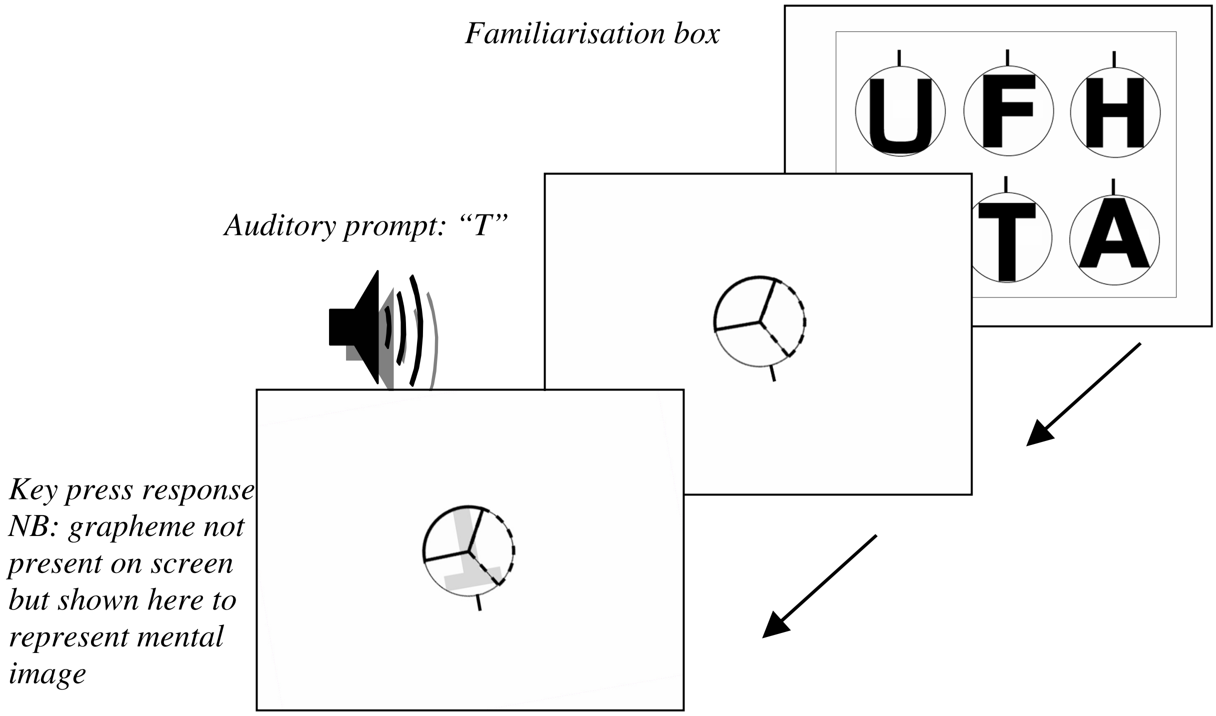


Fig 5.1: Trial procedure for Object Task and Resolution Task in Experiment 4

The Resolution Task was also expected to use an object-imagery process and so the same predictions were made for the individual synaesthetes as described for the Object Task. In the Resolution Task participants were again required to form a mental image of a grapheme and make a size based decision about that grapheme (see Figure 5.1). However, the rate-limiting process for this task was the level of detail required within the mental image; although the graphemes used by this task could be considered less complex than those used in the Object Task (consisting of three or fewer composite parts, e.g. L, T etc.), the task required participants to form an image with a higher level of resolution (i.e. to make the correct forced-choice decision the level of detail needed to be high). It was hypothesised that the Resolution Task would be likely to make use of the early visual processes, as image resolution has been shown to be one of the predicting factors for activation of these areas with a mental image (Kosslyn & Thompson, 2003). Therefore, a mental image with a higher level of detail / resolution would be likely to stimulate the primary visual cortex, allowing the image to be processed by the subsequent visual areas as a whole, as if it were a visual percept. Consequently, as the Resolution and Object Tasks were very similar and differed only in terms of their rate-limiting process, any difference found in strength of congruency effect for an individual between the two tasks would indicate the importance of that rate-limiting process to the generation of a synaesthetic concurrent from a mental image of an inducer.

The Transformation Task was expected to use a spatial imagery process. The task involved the same image generation and size-based decision as the Object and Resolution Task, but prior to making the size-based decision participants needed to mentally rotate the grapheme within each image to one of four possible indicated positions (see Figure 5.2). The rate-limiting process with this task was therefore image transformation. As outlined earlier, image transformation processes are thought to utilise the spatial pathways within the visual system, and studies requiring the mental rotation of visually presented graphemes have shown activation in the parietal cortex to be important (for example, Harris & Miniussi, 2003). Importantly, whereas in Experiments 2 and 3 the grapheme was visually presented on the screen for the participants to mentally rotate, the current Transformation Task required the initial generation of the grapheme image prior to the transformation needed to make the relevant forced-choice decision. The transformation process was the anticipated rate-limiting feature of this task, and so it was hypothesised that there would be significant congruency effect for DS, KD, RW and VE, with the congruent condition being slower than the incongruent condition for DS, KD and RW, while the ‘no colour’ condition was predicted to be slower for VE.



Familiarisation box

Auditory prompt: “T”

Key press response
NB: grapheme not present on screen but shown here to represent mental image

Fig 5.2: Trial procedure for Transformation Task in Experiment 4

The Spatial Task required participants to use spatial imagery processes to recall the relative location of a grapheme (see Figure 5.3). The rate-limiting process for the Spatial Task was therefore image scanning ability. Previous mental imagery studies have made use of the image scanning paradigm to show that the time taken to scan from one point on a mental image to another point increases as the distance increases (Borst, Kosslyn, & Denis, 2006), and that this rate of increase correlates with that found with perceptual representations of the same scene (Borst & Kosslyn, 2008). Importantly, it has been suggested by Borst and Kosslyn (2008) that these image scanning processes are unlikely to involve the early visual areas, and are more likely to rely on spatial processes. They suggest that the parts of the posterior parietal lobes that have been found to be topographically organised (see Sereno, Pitzalis, & Martinez, 2001) could be important for representing the spatial layout of images. Consequently, although synaesthesia from image scanning has not been explored before, based on the premise that image scanning processes, like image transformation processes, utilise the dorsal pathway, the same predictions were made for the individual synaesthetes as described for the Transformation Task.

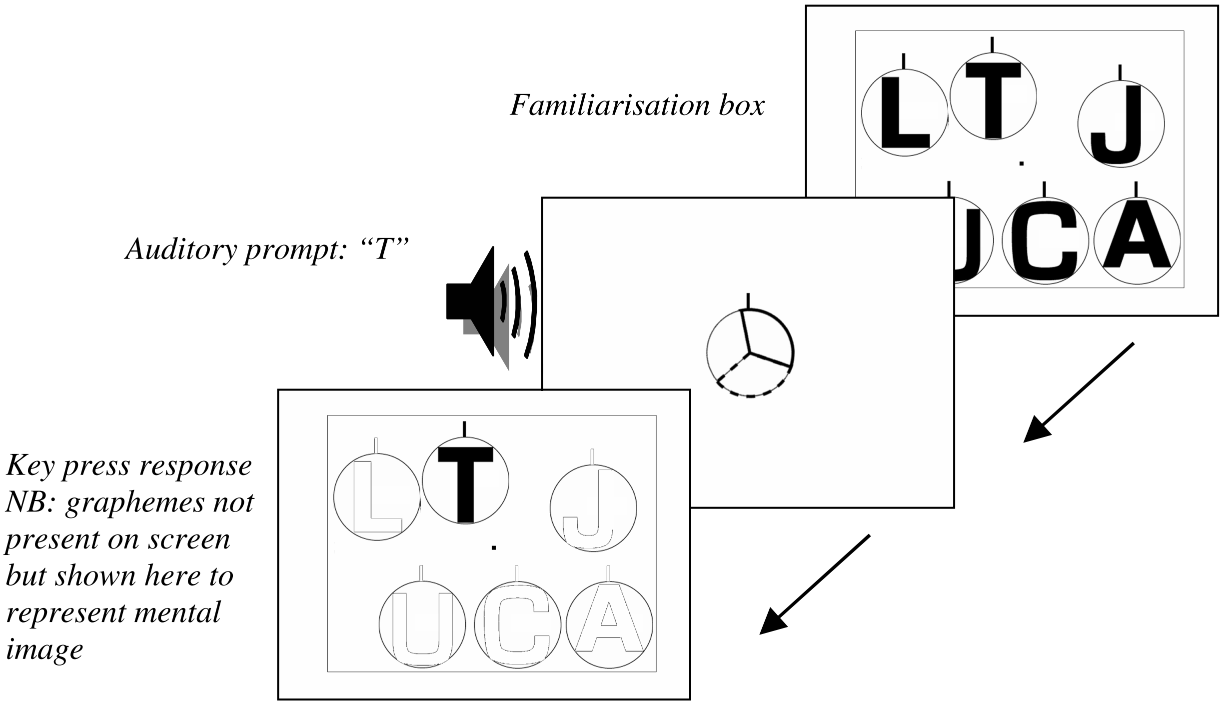


Fig 5.3: Trial procedure for Spatial Task in Experiment 4

In the Visual Task participants were required to make a similar size-based decision to that used in the Object and Resolution Tasks. However, as the grapheme was visually presented within the circle in each trial, the task used visual perception rather than mental imagery processes (see Figure 5.4). As visual perception and mental imagery are thought to make use of about 90% of the same brain areas (Ganis, Thompson, & Kosslyn, 2004) it was expected that if the background colour was found to have had an effect on task performance, then the synaesthetes would perform in a similar way to how they performed in Experiment 1. Therefore it was hypothesised that, as found in Experiment 1, there would be a significant congruency effect for synaesthetes RW, DS, and VE, with the congruent condition being faster than the incongruent condition for RW and DS, and vice versa for VE. It was also expected that an individual synaesthete’s performance on the Visual Task would be very similar to their performance on the Resolution Task, as that task in particular was expected to activate the early visual processes due to the high level of image resolution required to successfully complete the imagery task.

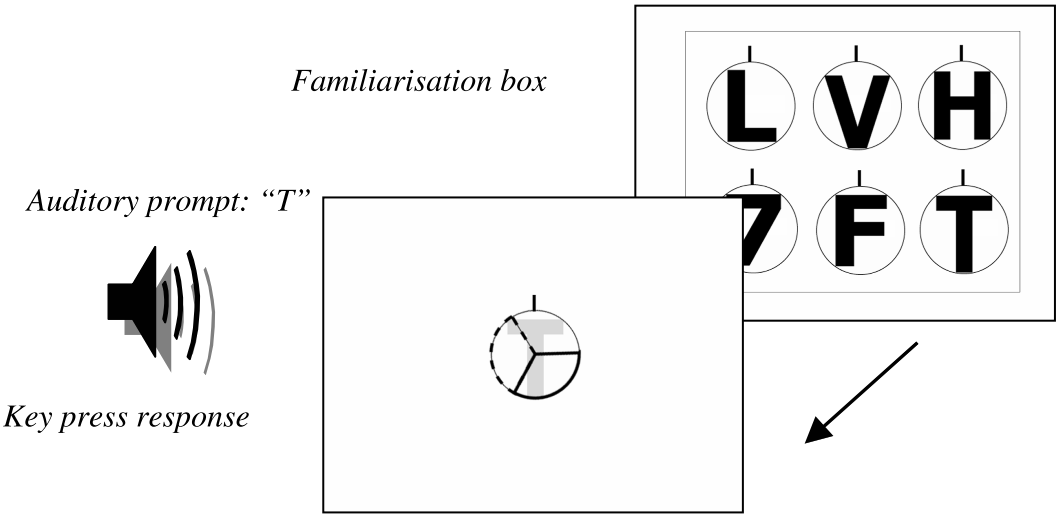


Fig 5.4: Trial procedure for Visual Task in Experiment 4

5.2: Experiment 4 Method

Participants

In the current study there were five grapheme-colour synaesthete participants (KD, DS, RW, VE and ZV). All of the synaesthetes had completed earlier experiments (please see Table 2.1 for their details).

Materials

The battery consisted of a familiarisation task and five trial tasks (four mental imagery tasks and one visual task), which were run on a PC using the software E-Prime. The tasks were modified versions of the Visual Cognition Battery (Kosslyn, Shephard, Burrage, & Thompson, 2006). Two of the tasks in the

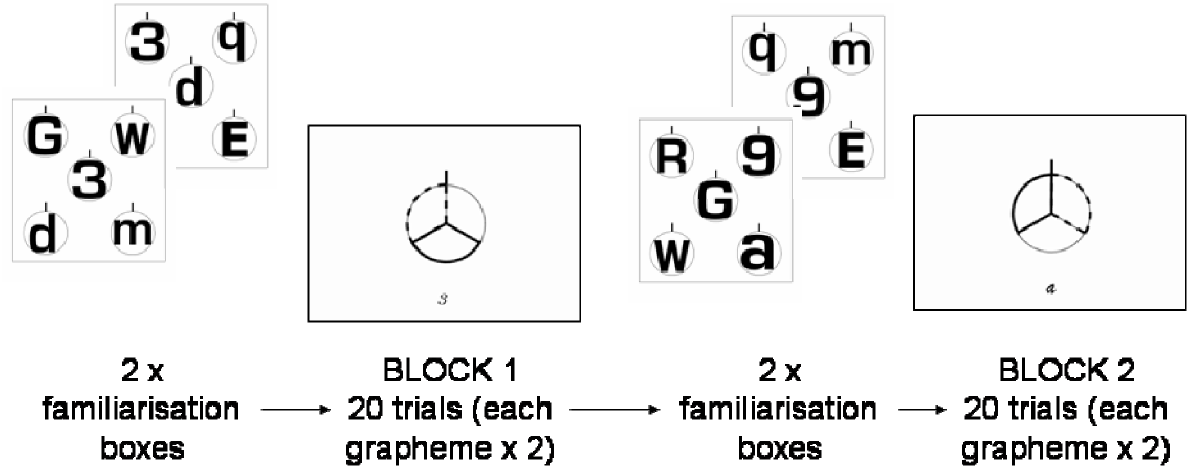
Visual Cognition Battery were adapted from tasks used by Kosslyn et al (2004) and Ganis et al (2005). All of the tasks in the battery had been developed by the authors so that the trials were of approximately equal difficulty within the tasks, and that the key difference between the tasks was the imagery process required for completion for the trials.

Familiarisation Task: During the familiarisation task each of the fifteen letters and three digits to be used in the upcoming tasks were displayed in black within a circle, in the centre of a white computer screen.

Trial tasks: The tasks were kept as similar as possible to the original set of tasks within the Visual Cognition Battery, but necessary modifications were required to make the tasks as suitable as possible for the aims and requirements of the current study. Whereas in the original Visual Cognition Battery the background remained white throughout, for the purpose of the current study this was changed so that the background colour varied across trials so that it was achromatic or was congruent, incongruent, or opponent to the synaesthetic colour of the grapheme being visualised for that trial. The background colours were individually designed for each synaesthete so that appropriate colours were used (based on the colour information given in the pre-test assessment as described in the procedure section of Experiment 1). The incongruent colour matched the colour for one of the other graphemes used within that task that was perceptually/visually different to the congruent colour. The opponent colour, as described earlier, was calculated by converting the RGB values (as taken by the colour selections provided by the synaesthetes) into hue, saturation and lightness (HSL) values, and using the formula “*H' = (H + 128) modulus 256*”, where H is the hue value for the congruent colour, and H' is the complementary hue (with lightness and saturation remaining the same) and ‘modulus 256’ ensures that the new value of H' remains within the given values of 0 and 255 ("Complementary Colours: RGB to HSL", 2006).

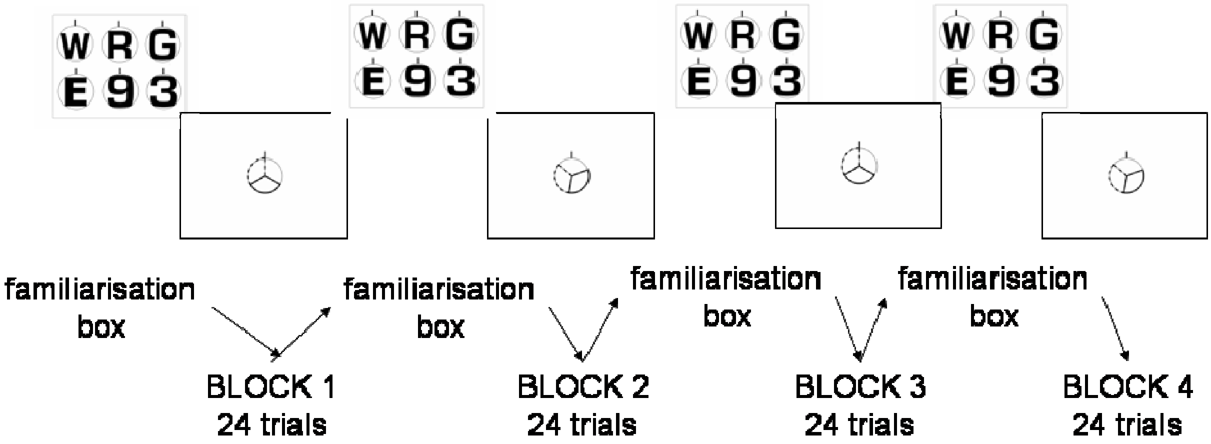
Further modifications included changing the visual grapheme prompt to an auditory one, meaning that the only stimulus visually presented to the participants during the trials was the circle divided into three sections. Another modification was the use of only upper case letters. Whereas the original battery has used both lower and upper case letters it was decided that only upper case letter would be used in the current tasks, allowing a more straightforward auditory prompting method. Additionally, although lower and uppercase graphemes have been reported to generally induce the same concurrent (Grossenbacher & Lovelace, 2001) uppercase graphemes have been reported to produce more saturated concurrents in a single-case study (Witthoft & Winawer, 2006). Consequently, there were fewer available graphemes, reducing the total number from 10 to 6 for the Object Task, and from 20 to 14 for the other tasks (Resolution, Transformation, Spatial and Visual). All of the six possible graphemes were used for the Object Task (‘E’, ‘G’, ‘R’, ‘W’, ‘3’, ‘9’). Of the 14 available graphemes for the other tasks, 12 were selected for use (‘A’, ‘C’, ‘D’, ‘F’, ‘H’, ‘J’, ‘L’, ‘T’, ‘U’, ‘V’, ‘Y’, ‘7’) to keep the same ratio of 1:2 graphemes as used in the Object Task compared to the other tasks in the original battery. The graphemes not selected for use were ‘1’ and ‘X’ as research has shown that there is a trend for these graphemes to induce black or white (Simner et al., 2005) which would be more difficult to use as background colours. Importantly however, changes were not made to each grapheme's visual presentation during the familiarisation stage e.g. size, font and position in the circle were kept the same.

Due to this reduction in the number of stimuli, changes were also needed to the familiarisation boxes shown at the start of each trial block. In the original tasks, participants were shown two familiarisation boxes prior to each trial block, each containing five of the ten graphemes to be used in the up-coming trial block (see Figure 5.5). In the current study there was one familiarisation box prior to each trial block containing all of the six graphemes to be used in the up-coming trial block (see Figure 5.6). Therefore, whereas in the original tasks there were two trial blocks, each consisting of 20 trials, in the current study each task had four trial blocks, each consisting of 24 trials. Of the possible twelve graphemes in the current Resolution, Transformation, Spatial and Visual Tasks, six were used in Blocks 1 and 3, and the other six were used in Blocks 2 and 4.



Original Object Task: 10 graphemes (a, d, E, G, m, q, R, W, 3, 9) each used with 4 different trisected circles = 40 trials in total

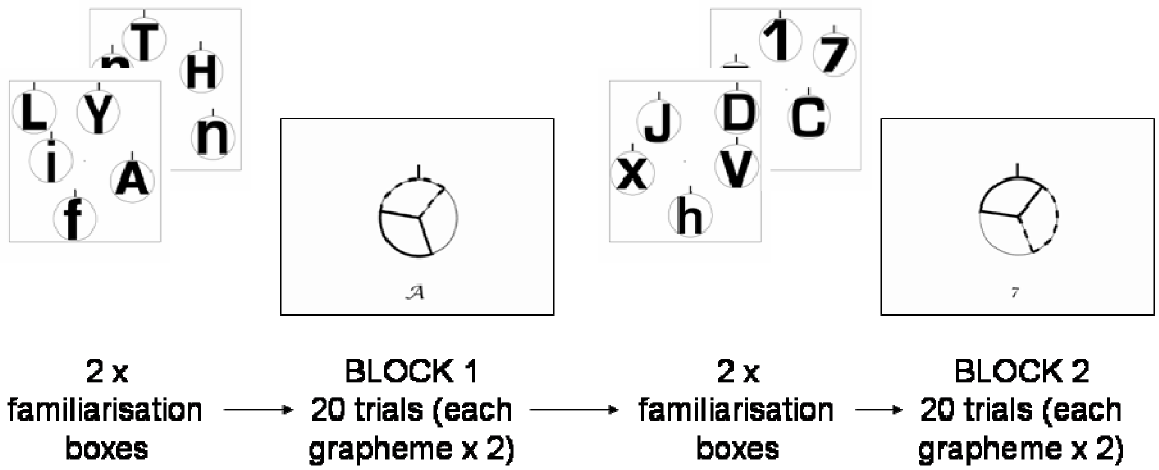
Fig 5.5: Sequence of events in Object Task from original Visual Cognition Battery



Current Object Task: 6 graphemes (E, G, R, W, 3, 9) each used with 4 different trisected circles, in 4 different colour conditions = 96 trials in total

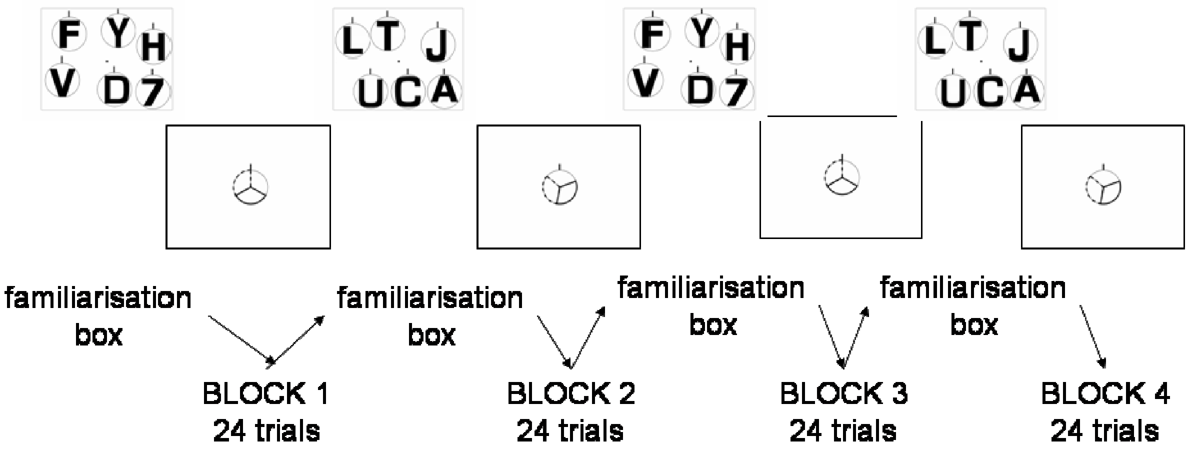
Fig 5.6: Sequence of events in Object Task as used in Experiment 4

Changing the number of graphemes in each familiarisation box meant that the appearance of these boxes was different, causing important implications for the Spatial Task. As participants were required to recall the visual location of each grapheme in the familiarisation boxes in the Spatial Task, modified boxes were carefully created. As before, the graphemes were placed around a dot in the centre of the box in a non-uniform pattern (see Figure 5.7 and 5.8).



Original Spatial Task: 20 graphemes (A, C, D, f, F, h, H, j, J, l, L, n, r, T, U, V, X, Y, 1, 7) each used with 2 different trisected circles = 40 trials in total

Fig 5.7: Sequence of events in Spatial Task from original Visual Cognition Battery (including original versions of familiarisation boxes to mentally scan during subsequent trials)



Spatial Task: 12 graphemes (A, C, D, F, H, J, L, T, U, V, Y, 7) each used with 2 different trisected circles, in 4 different colour conditions = 96 trials in total

Fig 5.8: Sequence of events in Spatial Task as used in Experiment 4 (including new versions of familiarisation boxes to mentally scan during subsequent trials)

Removing the lower-case graphemes also affected the ratio of each type of correct response given (i.e. the number of times the correct response is ‘thick’ and the number of times the correct response is ‘dashed’). However upon inspection it was found that there was only a slight imbalance of responses (ratio of thick-to-dashed responses for the Object Task = 50:50, for the Resolution Tasks = 54:46, for the Transformation Task = 50:50, for the Spatial Task = 51:49 and for the Visual Task = 46:54, giving an overall ratio of 50.2:49.8). It was therefore decided that this slight imbalance was a necessary requirement for the overall needs of the study.

To summarise, necessary modifications were made to the overall design of the tasks in the current study. However, every attempt was made to keep the tasks in the current study as similar as possible to those used in the original battery. For example, in Experiments 1 to 3, participants gave a spoken response to each trial, but as the original Visual Cognition Battery had used a key press response it was decided that this would be used for the tasks in Experiment 4 as well. Other important aspects which were not modified included the overall general procedure of each task, the trials used (except for the Spatial Task as described above) and the response procedure.

Procedure

After giving informed consent, participants completed the Familiarisation Task. In this task each grapheme was displayed within a circle on the computer screen, as it was to be visualised during the subsequent trials tasks. The grapheme remained on the screen for 4000ms, and participants were asked to study the grapheme carefully, paying close attention to the exact shape, size and location of the grapheme within the circle (see Figure 5.9). Subsequently, the grapheme disappeared, leaving an empty circle, and participants were asked to take as much time as needed to visualise that grapheme within the circle. When they felt that they had made their image as clear and vivid as they could, they were told to press the space bar for the grapheme to reappear. At this point, they were asked to carefully compare their visualised image to the actual grapheme on the screen, and to correct their mental image if necessary. They then pressed the space bar again to move on to the next grapheme where the process was repeated until all 18 graphemes to be used in the upcoming tasks had been practiced in this way. The written instructions provided before completion of the familiarisation task stressed that for the success of the study it was essential for the images of the graphemes formed in the subsequent trial phases to be the same as the pictures of the graphemes presented in the Familiarisation Stage (see Appendix D).

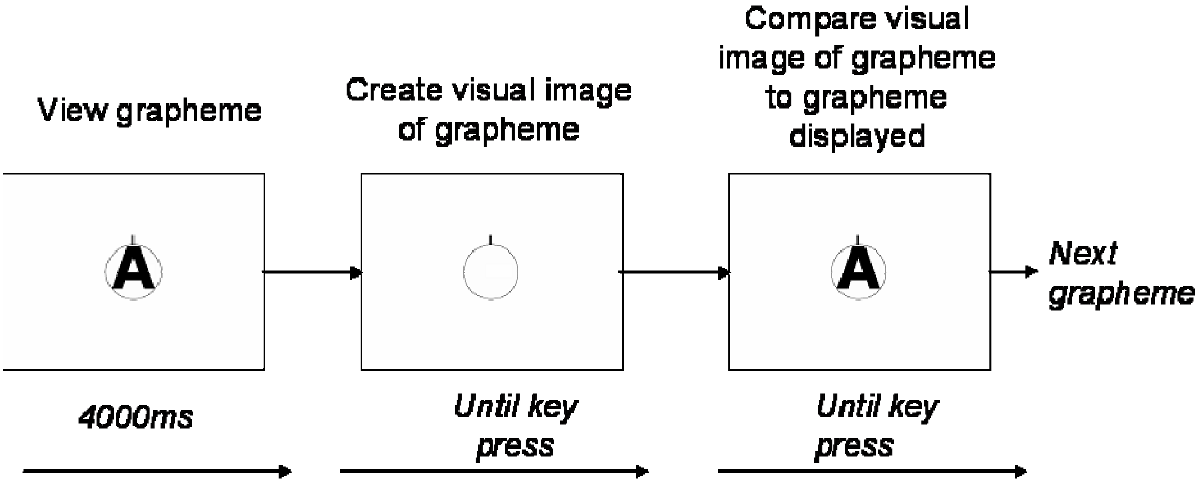


Fig 5.9: Example of procedure used in the Familiarisation Task in Experiment 4 to practice forming an image of a grapheme

The participants then completed the five trial tasks in the following order; ‘Object Task’, ‘Resolution Task’, ‘Transformation Task’, ‘Spatial Task’ and ‘Visual Task’ (see Figures 5.1 to 5.4). Prior to each task there were written instructions (see

Appendix D), with an example, and they completed six practice trials (with additional accuracy feedback). In all tasks, the trials began with a ‘familiarisation box’ being shown on the screen which showed six graphemes. Participants were told that these graphemes were to be used in the subsequent 24 trials, and to study this box as needed. Following this, participants were presented with the first block of 24 trials. In total there were two different familiarisation boxes in every task, shown alternatively before each of the four trial blocks (as shown in Figure 5.6 and 5.8). Each grapheme was presented an equal number of times in each of the four colour conditions. The 96 trials were presented in a pseudo-random order across the four trial blocks, ensuring that the same grapheme was not used in two repetitive trials. For all tasks participants were asked to complete each trial as quickly as possible without sacrificing accuracy. Each selected response and time to respond were recorded by the computer.

Object Task: In this task each trial consisted of a circle appearing on the computer screen that was divided into three equal sections (see Figure 5.1). One section of each circle had a thick line around it and another had a dashed line around it. An auditory prompt was given at the same time as the circle was presented, indicating the grapheme to visualise for that trial. Participants were asked to visualise this prompted grapheme within the divided circle on the screen, as carefully and precisely as possible. They were then to decide which section of the circle, the thick or dashed section, would have more of its area covered by the visualised grapheme, responding by pressing the appropriate key on the keyboard. The six graphemes used within the Object Task consisted of four or more ‘strokes’; ‘3’, ‘9’, ‘E’, ‘G’, ‘R’, ‘W’.

Resolution Task: For this task the procedure and decision was the same as used in the Object Task (see Figure 5.1). However, the trials in this task required a high level of resolution in order to make the correct decision and the 12 graphemes used consisted of three or fewer ‘strokes’; ‘7’, ‘A’, ‘C’, ‘D’, ‘F’, ‘H’, ‘J’, ‘L’, ‘T’, ‘U’, ‘V’, ‘Y’.

Transformation Task: In this task the trials again had the same procedure as the Object Task, but each circle had a small mark/tick in one of four locations on its circumference (see Figure 5.10). Participants were told to mentally rotate their mental image of the grapheme so that the top of the grapheme was in line with this mark, before making the same decision as in the Object Task (see Figure 5.2). The Transformation Task used the same graphemes as the Resolution Task.

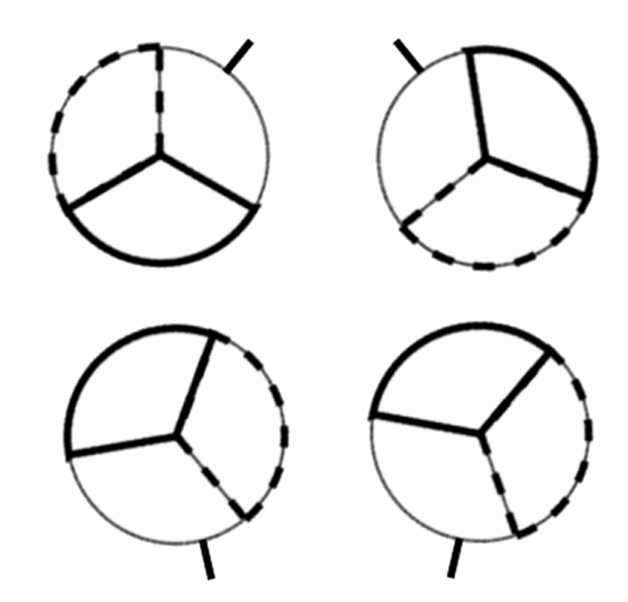


Fig 5.10: Examples of the four different locations of the ‘mark’ on the circle circumference indicating angle to rotate prompted grapheme in Experiment 4’s Transformation Task. Note: an equal number of trials had the mark located in the top and bottom half of the circle, and positions of thick/dashed sections of divided circle were not restricted to the examples shown.

Spatial Task: Again the trials had the same basic procedure, but there were important differences. The first was that the graphemes in the familiarisation boxes were not evenly spaced in the box, but instead were ‘scattered’ around a central dot within the box (see Figure 5.3 and 5.8). Before starting the trials participants were asked to take as much time as needed to study the spatial location of each grapheme in relation to the central dot, as they needed to recall these locations during the upcoming trial block. During the trials they saw a series of circles divided into sections, as before, and heard an auditory prompt corresponding to one of the graphemes within the circles in the familiarisation box. For each trial, they were asked to visualise the prompted grapheme’s spatial location in the previously studied familiarisation box and, by pressing the appropriate labelled key, indicate which section of the circle (the ‘thick’ or ‘dashed’ section) they thought would have fallen closest to the box's centre point by mentally scanning the image from the grapheme to the centre point (as shown in Figure 5.3 – see Spatial Task Instruction in Appendix D for an additional illustrative example). The Spatial Task used the same graphemes as the Resolution Task.

Visual Task: in this task the same procedure was used as the Object Task, but in these trials, in addition to the auditory prompt, the actual grapheme was visually presented within the divided circle (see Figure 5.4). Therefore it was a visual decision, and imagery was not required. The Visual Task used the same graphemes as the Resolution Task.

5.3: Experiment 4 Results

For all tasks the mean response time (RT) for each condition was calculated using trials answered correctly. Trials that were treated as outliers (using stem and leaf procedures from SPSS package 10.1) were removed independently for all conditions. This procedure resulted in the removal of between 2% and 5% of trials per synaesthete across all tasks. The data for each synaesthete have again been considered separately for each synaesthete. As the tasks were thought to involve distinct imagery processes these were initially considered independently. There were two types of ‘incongruent’ conditions providing two types of congruency effect; (1) the ‘standard’ congruency effect (CE-S) which was calculated by subtracting the mean RT for the incongruent trials from the mean RT for the congruent trials, and (2) the ‘opponent’ congruency effect (CE-O) which was calculated by subtracting the mean RT for the opponent trials from the mean RT for the congruent trials. One-way ANOVAs were used to explore the overall effect of colour on RT, and Levine’s test was used to assess that the assumption of homogeneity had been met for each analysis ($p < .05$). Bonferroni post-hoc comparisons ($p < .05$) were used to further explore main effects of colour. For the separate tasks, error rates (ERs) were calculated for each synaesthete, and these are presented for the four colour conditions for each task. RTs and ERs were correlated to check for any possible speed-accuracy trade-offs.

Object Task: Results and Discussion

Table 5.1a shows the Object Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. As can be seen in this table, the two types of congruency effect varied in direction for individual synaesthetes, so for example a synaesthete with a positive standard-CE had a negative opponent-CE, and vice versa. Analysis of the effect of colour on Object Task performance found that for ZV the effect of colour approached significance ($F(3, 69) = 2.54$, $p = .064$, $\eta^2 = .1$). Post hoc comparisons suggested that the difference between the ‘no colour’ and incongruent trials approached significance ($p=.059$) with the incongruent condition being slower. For RW the assumption of homogeneity of variance was found to be violated ($F(3, 74) = 5.15$, $p = .003$) therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was not found ($F(3, 49) = 1.97$, $p = .13$, $\eta^2 = .08$). For KD the assumption of homogeneity of variance was also found to be violated ($F(3, 75) = 3.56$, $p = .018$) and therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was not found (F(3, 65) = 1.57, p = .21, η^2 = .06). For VE a significant effect of colour was not found (F(3, 74) =1.32, p = .28, η^2 = .05) and for DS the effect of colour was not significant (F(3, 78) = 1.32, p=.27. η^2 = .05). Consequently, the hypothesis that there would be a reliable effect of colour on the synaesthetes Object Task performance was only supported for ZV.

Table 5.1a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Object Task in Experiment 4

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
RW	2729 (639)	2691 (437)	2770 (656)	3203 (1044)	37	-41
VE	2379 (569)	2734 (967)	2342 (543)	2640 (818)	-355	37
KD	2910 (1397)	3235 (1642)	2397 (799)	2545 (1377)	-325	513
DS	3658 (1590)	3374 (1167)	4081 (1349)	4116 (1543)	284	-423
ZV	3622 (1019)	4039 (659)	3486 (801)	3317 (889)	-418	136

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed across the colour conditions (see Table 5.1b). Of particular interest for the current analysis is ZV's ER, and importantly this shows that there was very little difference between the ERs for the incongruent and 'no colour' conditions. Therefore the interpretation of the RT analysis for ZV was not compromised by a speed-accuracy trade-off. Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all *p*s > .05) indicating a general absence of speed-accuracy trade-offs.

Table 5.1b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Object Task in Experiment 4

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
RW	14	4	2	2	6
VE	15	3	4	3	5
KD	10	3	3	2	2
DS	12	4	3	1	4
ZV	20	7	3	6	4

Object Task Discussion: The Object Task was expected to use object-imagery processes and the specific rate-limiting process related to the complexity of the object within the image; the ability to form images of graphemes with more composite parts. It was predicted that background colour would affect task performance, and as the task was very similar to the imagery task used in Experiment 1, predictions were made about the direction of this effect for the synaesthetes previously showing a significant colour effect. RW and DS were expected to be faster in the congruent trials than the incongruent trials and VE was expected to be faster in the incongruent trials than the congruent. However, the results for these synaesthetes did not support these predictions.

Importantly, not only were the colour effects not statistically reliable, they did not go in the direction predicted. A colour effect approaching statistical significance was found with ZV. Her results suggested that when the background colour was incongruent to the one she was visualising, she was particularly affected by the addition of colour to the task. Interestingly, she was not affected by the opponent colour in a similar way. Consequently, there are two main discussion points for the Object Task; first, potential explanations for the lack of support for the predicted colour effect with particular synaesthetes, and second, likely reasons for the unexpected colour effect for ZV, focusing on the implications of the difference between the incongruent and opponent conditions.

A number of explanations can be put forward as to why the synaesthetes that had previously shown an effect of colour on a similar imagery task in Experiment 1 did not show the same effect of colour with the Object Task. First, the tasks differed in a few important ways, such as the choice of graphemes and the actual task procedure. Choice of graphemes is unlikely to be the reason for the lack of significant effect however, as although the selection criteria for the graphemes differed between the two tasks, one letter was selected for both tasks (‘E’), for which the unexpected pattern of results was also found. Another important difference relates to the task procedure. In Experiment 1’s imagery task each trial had two distinct stages; an ‘image-forming stage’ in which participants formed the image of the prompted grapheme within a circle on a white computer screen, and a ‘decision-making stage’ in which the background colour was manipulated, the circle appeared divided, and participants made the size-based decision (see Figure 2.1). When the congruent and incongruent colours were presented to the synaesthetes, the initial image of the grapheme had already been formed. The colour effects found Experiment 1 therefore reflected the potential impact of the presentation of these colours, in addition to the amount of time taken to make the decision. In contrast, the trials in the current Object Task, as with all tasks in Experiment 4, did not have a distinct 'image-forming' stage (see Figure 5.1). Consequently, the initial image was formed whilst looking at the various background colours and the potential impact of the colour was present from the start of each trial. Therefore, differences in response time between colour conditions in the current tasks may reflect the effect colour had on initial image formation in addition to the subsequent decision-making time.

Other explanations for the lack of expected colour effect relate to the actual mental imagery process used. Although the Object Task is thought to use object imagery processes, the top-down processes required for the rate-limiting process would not be expected to necessarily propagate back to the early visual areas. Research has suggested that, in relation to mental imagery, areas within the retinotopically organised early visual cortex are activated when a high resolution image is formed and inspected (Kosslyn & Thompson, 2003). As the rate-limiting process for the current task was image complexity, it did not necessitate the formation of an image with a high level of resolution, and so a topographical representation of the grapheme was unlikely to have been formed within these early visual areas. Some researchers have argued that the functional significance of such activation allows the fine spatial binding of the features of the object within the mental image, allowing it to be processed through the visual system as if it was an object perceived externally (Klein et al., 2004). Using this logic, it could be argued that while the imagery task in

Experiment 1 may have activated these early visual areas, resulting in synaesthetic concurrent from the processing of the grapheme image for some synaesthetes, the grapheme image in the current Object Task was not processed at this level and so the concurrent was not elicited for these same synaesthetes. Consequently, this would provide support for the importance of the visual processing of the grapheme form, and the role the early visual areas play in the generation of a synaesthetic concurrent as suggested by the Cross-Activation Theory (Hubbard & Ramachandran, 2005).

As the rate-limiting process of the Object Task was image complexity, it could be speculated that this task required greater attention, and this was the reason for the lack of expected colour effect. Previous imagery research has found that images of graphemes with more composite parts take longer to form than images of graphemes with fewer parts (Kosslyn, Cave, Provost, & von Gierke, 1988), and so it would be possible to argue that this would require a higher level of cognitive effort, or attention. As described in earlier chapters, previous synaesthesia research has shown that manipulating the attentional resources available when processing a grapheme has an impact on the generation of the synaesthetic concurrent; when there are fewer cognitive resources available due to a more demanding task, the synaesthetic concurrent has a smaller impact on the task performance (Mattingley, Payne, & Rich, 2006). It would therefore be expected that an imagery process that involves creating more complex images, and hence requires a higher level of cognitive effort, would be less affected by the synaesthetic concurrent as there are fewer resources available for processing irrelevant perceptual stimuli, which in this case would be the background colour. Interestingly, support for this idea was not found with the mental rotation tasks used in Experiments 2 and 3, in which the trials that required greater levels of attention produced larger congruency effects. However, the mental rotation tasks required the use of spatial processes, whereas the Object Task purportedly utilised object imagery processes. It is therefore possible to speculate that when the attentional demands were spatial they resulted in a stronger congruency effect, as shown with Experiments 2 and 3, whereas the potentially greater object imagery demands in the current Object Task resulted in a less evident congruency effect than found with the imagery task presented in Experiment 1.

The second main discussion point from the Object Task results was the unexpected finding for one of the synaesthetes. Although no predictions about direction of effect were made for ZV an effect of colour that approached significance was found for her with the Object Task. She was fastest in the ‘no colour’ condition, and slowest when the background colour was incongruent to the synaesthetic colour. This suggests that when the background colour matched the synaesthetic colour of another grapheme she was particularly affected by the addition of colour to the task. A possible interpretation of the results relates to the synaesthesia studies which suggest viewing an incongruently coloured grapheme use more attentional processes (Paulsen & Laeng, 2006; Weiss, Zilles, & Fink, 2005). It could therefore be argued, as it was in earlier chapters, that visualising a grapheme against an incongruently coloured background would result in a reduced processing capacity, and subsequently in the slower response time for these trials in the Object Task. However, as noted earlier, ZV was not affected by the opponent colour in a similar way. Therefore it was not simply having the wrong colour that affected task performance, suggesting an important difference between using colours from within a synaesthete's own 'colour alphabet' and colours that do not appear in their 'colour alphabet'. An alternative explanation for the current results could be that when ZV was visually presented with a colour usually 'experienced' with a different grapheme, her performance was slowed, because it made her think of the grapheme usually 'experienced' with that colour, as found with the bi-directionality studies (for example, Cohen Kadosh & Henik, 2006). However it needs to be kept in mind that the difference was only approaching significance, and colour was found to account for only 10% of the response time variability. Also, in Experiment 1, although the difference was not statistically significant, the congruent condition was found to be the slower of the two coloured conditions, so the opposite direction to that found with the Object Task.

In summary, the findings from the Object Task did not go in the directions predicted. The differences observed between the colour conditions were relatively small and were not found to be statistically reliable. Overall support was not found for the idea that there would be a measurable synaesthetic experience from the imagery processes used in the Object Task. For one of the synaesthetes it would seem that the incongruent condition was a hindrance to task completion, and it was when the background colour 'belonged' to another grapheme that there was the most disruption. Interestingly however, this effect had not been found with the imagery task used in Experiment 1.

Resolution Task Results and Discussion

Table 5.2a shows the Resolution Task mean RTs for individual synaesthetes across the three colour conditions with their associated CEs; it can be seen that the effect of colour again varied across the synaesthetes. For RW, the effect of colour was found to approach significance (F(3, 66) = 2.54, p = .06, (η^2 = .1). Post-hoc tests revealed that the difference between the 'no colour' and incongruent conditions approached significance (p=.08) with the incongruent condition being faster. Additionally, direct comparison of the congruent and incongruent conditions found that the incongruent condition was significantly faster than the congruent, (t(32) = 2.42, p = .022, *d* = 0.83). For DS the assumption of homogeneity of variance was found to be violated (F(3, 78) = 3.76, p = .014) and therefore the Brown-Forsyth F ratio is reported. A significant effect of colour was found (F(3, 59) = 4.05, p = .011, η^2 = .14). Post-hoc tests showed a significant difference between the incongruent and 'no colour' conditions (p =.008), with the 'no colour' condition being faster than the incongruent condition. A significant effect of colour was not found for VE (F(3, 75) = 1.42, p = .24, η^2 = .06), for KD (F(3, 66) = 0.76, p = .52, η^2 = .03), or for ZV (F(3, 75) = 1.03, p=.38, η^2 = .04). Therefore, there was some support for the hypothesis that the background colour would affect performance on the Resolution Task with RW and DS.

Table 5.2a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Resolution Task in Experiment 4

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
RW	2823 (821)	2213 (642)	2848 (964)	2939 (992)	610	-25
VE	2537 (951)	2417 (830)	2302 (717)	2039 (605)	120	235
KD	1980 (911)	2407 (853)	2454 (1172)	2428 (1009)	-427	-474
DS	3850 (1314)	4364 (1937)	3328 (1248)	2943 (957)	-515	522
ZV	3519 (959)	4061 (1182)	3627 (1380)	3449 (1184)	-542	-108

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made did differ slightly across the colour conditions (see Table 5.2b). Of particular interest for the current analysis are the ERs for RW and DS. There was very little difference between the ERs for the incongruent and 'no colour' conditions for RW, and although DS made slightly more errors in the incongruent than 'no colour' condition, he was also found to be slower in the incongruent condition. Therefore the interpretation of the RT analysis for RW and DS was not compromised by a speed-accuracy trade-off. Additionally, there were no significant correlations between ERs and RTs for RW, VE, KD and DS (all *p*s > .05) indicating a general absence of speed-accuracy trade-offs. For ZV a strong positive correlation was found, suggesting that as her error rate increased, so did her time taken to respond (r = .96, p = .036). This therefore does not represent a speed-accuracy trade-off.

Table 5.2b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Resolution Task in Experiment 4

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
RW	23	7	5	7	4
VE	15	3	2	5	5
KD	25	9	5	4	7
DS	13	4	4	4	1
ZV	17	4	5	4	4

Resolution Task Discussion: The rate-limiting process of the Resolution Task related to the ability to form a mental image of a grapheme with a high level of detail, and was expected to use object imagery processes. As previous imagery research has suggested that activation of the early visual cortex is predicted by a mental image having a high level of resolution (Kosslyn & Thompson, 2003), it was proposed that the images formed in the Resolution Task may involve activation of these early visual processing areas. This potential involvement of these early visual areas was used to predict an effect of colour on the synaesthetes' performance, as it was hypothesised that the images of the graphemes would be processed in a similar way to an externally presented visual percept of a grapheme. Based on performances in Experiment 1 it was predicted that RW and DS would be slower in the incongruent than congruent condition, and vice versa for VE. As expected, DS was found to be significantly slower in the incongruent condition, while interestingly RW showed an effect of colour that approached significance, but not in the direction predicted. VE was found to be slower in the congruent trials than the incongruent ones as predicted, but the difference did not reach significance. Therefore, the three main points for discussion from the Resolution Task relate to the predicted colour effect for DS, the unexpected direction of colour effect for RW, and potential explanations for the lack of statistical support for VE's colour effect.

The significant effect of colour found with DS shows that the background colour affected his performance on the Resolution Task, and importantly as predicted, he was slowest when the background was incongruent with the grapheme being visualised. This therefore reflects the significant effect of colour found with his performance on the imagery task used in Experiment 1. Furthermore, the significant colour effect with the current Resolution Task implies that the lack of the predicted colour effect in the Object Task was more likely to be due to the imagery process required than task differences between the Object Task and Experiment 1's imagery task, such as the presence of an 'image-forming' stage. Assuming that the high resolution images formed during the Resolution Task were able to activate the early visual areas, and that the lower resolution images required for the Object Task did not, the results from these two tasks suggest that the early visual areas can play an important role in the generation of the synaesthetic concurrent for DS. In relation to the two main models of synaesthesia, these findings provide support for the role of visual processing in the cross-activation model (Ramachandran and Hubbard, 2001), as it highlights the importance of the processing in the early visual areas. If, as posited by the re-entrant model (Smilek et al, 2001), the concept was sufficient then one would predict the same colour effect to be found in both the Object and Resolution Task for DS, if as anticipated the only difference between the two tasks was a difference in the rate-limiting process.

Interestingly, the difference between the incongruent and congruent condition with the Resolution Task was not significant in itself, but rather it was between the incongruent and 'no colour' conditions. However, these results still add support to the idea that for DS it was difficult to form an image of a grapheme with high resolution against a background colour that matched the synaesthetic colour of a grapheme different to the one being visualised. This initially suggests that the incorrect colour was inhibiting his ability to form the image and/or make the size based decision required for the Resolution Task. Importantly however, the inclusion of the opponent condition shows that it was not a simple matter of having the 'wrong' colour background, but rather having a background that was normally experienced with a different grapheme. Trials in which the background colour was opponent to the synaesthetic colour of the grapheme being visualised were actually faster than the congruent condition. This provides support for the idea that the incongruent colour induced an idea of the grapheme that this colour 'belonged' to, and therefore suggests a potentially bi-directionality in his synaesthesia. This pattern of results is similar to that found with ZV in the Object Task, and it is interesting to note that although the effect did not reach the conventional level of significance, in the Resolution Task ZV was again found to be slowest in the incongruent trials. Therefore, unlike DS, ZV showed a similar colour effect on both the Object and Resolution Task. Although her results in the current task do not provide direct support for the role that the early visual processes play in the generation of a synaesthetic concurrent, as the Object Task also used object processes rather than spatial ones, the results still reflect the role of object processes more generally.

Surprisingly, the effect of colour for RW went in the opposite direction to that predicted. She was slowest to respond when there was ‘no colour’ in the background, and slightly faster in the opponent and congruent conditions, but the largest difference was between the ‘no colour’ and incongruent condition. Importantly, the incongruent condition was also found to be significantly faster than the congruent condition. This suggests that for RW it was easier to visualise a grapheme of a high resolution level against a colour that was associated with a different grapheme. As with DS, the fact that a significant effect of colour was found for RW with the Resolution Task suggests that the lack of ‘image-forming’ stage in the Object Task was not the reason for the small colour effect with that task, and the difference in imagery process is a more likely candidate. This again provides support for the idea that the early visual processes were important for the generation of a synaesthetic concurrent from a mental image of a grapheme. Without the inclusion of the opponent condition, it would have been possible to conclude that the difference in colour helped the grapheme to stand out, as predicted from the findings of Smilek et al (2001). However, as the same effect was not found for the opponent condition it seems that simply having the ‘wrong’ colour did not generally facilitate performance. Instead, having a background colour that was normally associated with a different grapheme to the one being visualised was beneficial. The lack of a distinct ‘image-forming’ stage is a potential explanation for the presence of this difference in direction of colour effect. When the ‘image-forming' stage was present in the imagery task in Experiment 1 RW was faster in the congruent condition than the incongruent condition, suggesting that after forming the grapheme image, the introduction of the incongruent colour in the 'decision-making' stage hindered her performance. In contrast, in the incongruent trials in the Resolution Task, as the colour was present from the start of the trial, RW may have been able to ignore the incongruent colour to focus on the imagery task. However, it is not clear why this would not be the case for the opponent trials, other than the idea that the opponent colours would be processed in the same colour channels as the congruent condition.

As predicted VE was found to be faster in the incongruent condition than the congruent condition, but this difference was not significant, and overall colour did not have a significant effect on her performance in the Resolution Task. One possible explanation for the difference between her performance in the current task and her performance in the earlier imagery task in Experiment 1 concerns the lack of an 'image-forming' stage in the current task. The potential 'camouflage effect' produced when the background colour matched the synaesthetic concurrent could potentially be more distracting if the colour was introduced after the image had been formed, than if it had been present from the start of the trial. It is also important to note that VE has taken part in all of the previous experiments, in addition to experiments with other synaesthesia researchers, and so the effect may not have reached significance with the current task due to her familiarity with the paradigm. However, another potential explanation to consider relates to the finding in the imagery literature that vivid mental images, which activate the early visual areas, can actually be found to 'de-activate' the higher multi-sensory areas (Amedi, Malach, &

Pascual-Leone, 2005). Whereas, with perception, the processing of external visual information benefits from, and indeed is modified by additional sensory information, Amedi et al have proposed that the differences in brain de-activation profiles between visual perception and mental imagery, suggest the isolation of the visual areas during purely 'visual' mental imagery processing. They argue that this is beneficial for vivid imagery, as it helps to prevent the distraction of irrelevant sensory processing from either other sensory systems, and even from external visual stimuli. Subsequently, the smaller congruency effect observed with VE in the Resolution Task, which required the formation and inspection of high resolution images, could be due to this 'isolation' of the early visual areas, resulting in a weaker interaction between the external presentation of the background colour and the synaesthetic concurrent. This argument therefore implies that the images of graphemes required for the task in Experiment 1 did not require such a high level of detail for VE to make the relevant size-based decision, preventing the isolation of these early visual areas.

To summarise, the findings from the Resolution Task again show the importance of treating the opponent and incongruent trials as separate conditions. Importantly, there was some support for the idea that visualising an image with a high level of resolution resulted in a measurable synaesthetic concurrent, as shown by RW and DS. As predicted, DS was slowest when the background colour matched the synaesthetic colour of another grapheme. Interestingly, for RW the direction of the colour effect was opposite to that predicted for the incongruent trials, as she was significantly faster when the background colour matched the synaesthetic colour of a grapheme she was not visualising.

Transformation Task Results and Discussion

Table 5.3a shows the Transformation Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can again be seen that the effect of colour varied across the synaesthetes. An effect of colour approaching significance was found for DS (F(3, 62) = 2.46, p = .07, η^2 = .11). Post-hoc tests showed that the difference of interest was between the congruent and 'no colour' conditions. Additionally, directly comparing the congruent condition with the opponent, found a trend (t(29) = 1.63, p = .1) that had a large effect size, (*d* = 0.6). One-way ANOVAs did not find a significant effect of colour for RW (F(3, 56) = 1.96, p = .13, η^2 = .095), for VE (F(3, 66) = 0.58, p = .63, η^2 = .03), for KD (F(3, 55) = 1.86, p = .15, η^2 = .09) or for ZV (F(3, 57) = 0.07, p = .98, η^2 = .004). However, when directly comparing the congruent with the opponent condition, KD was found to be significantly faster in the congruent condition (t(30) = 2.04, p = .05, *d* = 0.72). Additionally, the difference between the opponent and incongruent condition was found to be significant (t(27) = 2.47, p = .02, *d* = 0.96). Therefore, although for DS the level of significance did not reach the required level, the results indicate that his performance was substantially slower when the background colour matched the synaesthetic concurrent associated with the grapheme being visualised. In contrast, KD was faster when the background was congruent, and the difference between this condition and the opponent condition was significantly reliable. For the remaining synaesthetes background colour did not have an effect on task performance.

Table 5.3a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Transformation Task in Experiment 4

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
RW	3009 (1106)	3550 (1373)	2637 (826)	3168 (683)	-541	372
VE	2731 (870)	3088 (1012)	2708 (1280)	2645 (1141)	-357	23
KD	1970 (523)	1951 (319)	2329 (470)	2193 (671)	19	-359
DS	4525 (1610)	3963 (1740)	3670 (1226)	3194 (949)	562	855
ZV	4261 (1280)	4344 (1213)	4224 (1232)	4415 (1354)	-83	37

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made did differ slightly across the colour conditions (see Table 5.3b). Of particular interest for the current analysis are the ERs for DS and KD. Although DS made slightly more errors in the congruent than 'no colour' condition, he was also found to be slower in the congruent condition. Therefore the interpretation of the RT analysis for DS was not compromised by a speed-accuracy trade-off. KD did make slightly more errors in the congruent than opponent condition, and he was also faster in this condition, but as there was only a 2% difference it is unlikely that the RT interpretation would be greatly affected by a speed-error trade off. Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all *p*s > .05), indicating a general absence of speed-accuracy trade-offs.

Table 5.3b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Transformation Task in Experiment 4

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
RW	27	8	7	8	4
VE	27	7	6	6	8
KD	27	7	9	5	6
DS	25	7	4	9	5
ZV	34	11	8	7	8

Transformation Task Discussion: The Transformation Task was expected to use spatial imagery processes, and the specific rate-limiting process related to the ability to transform mental images of graphemes. Although image transformation is thought to have some depictive like qualities, various studies have shown that the processes involved are spatial rather than visual (Harris & Miniussi, 2003). The tasks used in Experiments 2 and 3 similarly required mental rotation processes. However, the benefit of the current Transformation Task was that it was directly comparable to the other tasks in the battery, in terms of involving the same size-based decision as the Object and Resolution Tasks, rather than the mirror-image discrimination task used in the earlier experiments. Additionally, the graphemes were all visualised in their 'normal' format, whereas half of the trials in Experiments 2 and 3 required the rotation of graphemes presented in an atypical visual form (backwards format).

Furthermore, the grapheme had been externally presented in the earlier tasks, whereas with the current task there was no visual presentation of the grapheme. The synaesthetes were therefore required to initially form the grapheme image before rotating it to its prompted position. It was predicted that the synaesthetes would show the same colour effects in the current Transformation Task as they had with the mental rotation tasks in Experiments 2 and 3. This was found to be the case for both DS and KD, who did show an effect of colour with the current task, but significant effects of colour were not found for RW or VE.

For KD, direct comparison of the opponent condition to the congruent and incongruent found the opponent condition to be substantially slower. As the incongruent condition was not slowed in the same way, the interference caused by the opponent colour was not due to simply being the ‘wrong’ colour. Using the logic of Nikolić et al (2007) these results could be used to suggest that there was a perceptual colour effect for KD, as when he transformed an image of a grapheme against a background that used the same colour channel as the synaesthetic concurrent elicited from that grapheme, he was slower than when it was both congruent and incongruent, suggesting that the levels of interference were greater for the opponent condition. Additionally, colour was found to affect DS’s performance, with the congruent condition being much slower than both the ‘no colour’ and opponent conditions (although only approaching significance). This is interesting as it suggests that when the background colour matched the synaesthetic colour he found the trials more difficult. This effect is the same as that found in the mental rotation task used in Experiment 2. Furthermore it was ‘opposite’ to his performance in the

Resolution Task, and also to the imagery task in Experiment 1, in which he was slower in the incongruent condition. As the rate-limiting process in the Transformation Task was thought to involve spatial imagery, and the Resolution Task was thought to involve object imagery processes, this difference in colour effect can again be used to suggest that for DS the type of imagery process plays an important role in the way the interaction between the synaesthetic colour and the ‘real’ colour influences task performance. When the task required a spatial imagery process he was slower when the background was congruent, suggesting a kind of ‘camouflage effect’. In contrast, when the task required an object imagery process he was slower when the background was incongruent, suggesting a ‘bi-directionality’ effect. Although it is not clear why this pattern of effects was found, it is important that this pattern is relatively consistent for DS across the experiments presented so far.

In summary, the Transformation Task again highlighted the importance of separating the opponent trials from the incongruent trials. Importantly for some of the synaesthetes mentally rotating an image of a grapheme did not result in a measurable synaesthetic concurrent. However, KD’s task performance was significantly impaired when the background was opponent to the concurrent elicited from the grapheme being transformed. Furthermore, for DS, a significant difference was found, and interestingly he was affected by the colours in the same way as he had on an earlier spatial imagery task (Experiment 2) but in a different way to the way the colour affected him in earlier object imagery tasks (the Resolution Task and Experiment 1).

Spatial Task Results and Discussion

Table 5.4a shows the Spatial Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can be seen that although the congruency effects differed in size for the incongruent and opponent conditions, the direction of the effect did not differ for an individual synaesthete (although the direction of effect did vary between synaesthetes). For DS, the assumption of homogeneity of variance was found to be violated (F(3, 76) = 7.51, p < .001) and therefore the Brown-Forsyth F ratio is reported. A significant effect of colour was found (F(2, 44) = 2.98, p = .041, η^2 = .11). Post hoc tests revealed that the difference between the congruent and ‘no colour’ conditions approached significance (p= .059) with the congruent condition slower than the ‘no colour’ condition. Additionally, directly comparing the congruent and incongruent conditions found the congruent to be the significantly slower of the two (t(26), = 2.02, p = .05, equal variances not assumed), and the effect size to be large (*d* = 0.7). For ZV, the assumption of homogeneity of variance was found to be violated (F(3, 71) = 4.6, p = .005) and therefore the Brown-Forsyth F ratio is reported. A significant effect of colour was found (F(3, 61) = 6.97, p < .001, η^2 = .22). Post hoc tests showed that there was a significant difference between both the incongruent and ‘no colour’ conditions (p=.028), and the opponent and ‘no colour’ condition (p<.001) with the ‘no colour’ having a slower RT than the other conditions. Furthermore, as ZV had a relatively large difference between the opponent and congruent condition further analysis showed that this difference was also statistically significant (t(37) = 3, p = .005, *d* = 1.01, equal variances not assumed), with the congruent condition having the slower RT. For VE, the assumption of homogeneity of variance was found to be violated (F(3, 78) = 5.59, p = .002) and therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was not found (F(2, 63) = 1.67, p = .18, η^2 = .06). However, when directly comparing the congruent and opponent conditions, the difference approached significance, with a large effect size, (t(31) = 1.88, p = .07, *d* = 0.6). The opponent condition, which was the slowest of the four conditions, was slower than the congruent condition. A significant effect of colour was not found for RW (F(3, 72) = 0.9, p = .45, η^2 = .04), or for KD (F(3, 77) = 0.49, p = .7, η^2 = .02).

Table 5.4a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Spatial Task in Experiment 4

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
RW	2852 (1219)	3480 (1596)	3377 (1483)	2998 (1150)	-628	-525
VE	2395 (547)	2540 (714)	2929 (1232)	2883 (1065)	-145	-534
KD	3255 (1103)	3560 (1226)	3678 (1463)	3693 (1470)	-305	-423
DS	4428 (2688)	3104 (1155)	3286 (1194)	2996 (1314)	1324	1142
ZV	3916 (1372)	3421 (1061)	2912 (624)	4561 (1384)	495	1004

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made did differ across the colour conditions (see Table 5.4b). Of particular interest for the current analysis is the ER for DS and ZV, and importantly this shows that for DS there was very little difference between the

ERs for the congruent and 'no colour' conditions, and for ZV between the opponent and 'no colour' conditions. Therefore the interpretation of the RT analysis for DS and ZV was not compromised by a speed-accuracy trade-off. Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all *p*s > .05) indicating a general absence of speed-accuracy trade-offs.

Table 5.4b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Spatial Task in Experiment 4

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
RW	19	4	4	4	7
VE	14	3	6	1	4
KD	10	1	3	1	5
DS	10	4	1	2	3
ZV	16	2	5	4	5

Spatial Task Discussion: The rate-limiting process with the Spatial Task was the ability to scan across spatial locations within a mental image. Previous findings from the imagery literature have suggested that image scanning processes, such as those used in the current task, use similar spatial pathways as those used by image transformation processes (i.e. the dorsal pathway in the occipital-parietal region) (Borst & Kosslyn, 2008). Therefore, it was anticipated that the findings for the Spatial Task would be similar to those from the

Transformation Task; it was predicted that manipulating background colour would have the same colour effect on each synaesthetes' ability to scan mental image locations as found with Experiments 2 and 3. For three of the synaesthetes, this was not the case, as colour was not found to have a significant effect on task performance for RW, VE or KD. However, a significant effect of colour was found for DS and also for ZV (who had not taken part in Experiments 2 and 3).

Interestingly, DS was slowest when the background colour matched the synaesthetic colour of the grapheme being visualised. Therefore, colour had the same effect on his performance in the Spatial Task as it did in the Transformation Task and Experiment 2, and so the opposite effect to the Resolution Task in which he was slowest in the incongruent condition. This supports the idea that for DS the tasks requiring spatial imagery processes elicited a synaesthetic concurrent, which specifically resulted in the task being more difficult when the background colour matched the colour of the synaesthetic concurrent. This suggests that when the background was congruent with the synaesthetic concurrent there was a camouflage effect, similar to that found by Smilek et al (2001) with a visual search paradigm that showed that synaesthetic concurrents could influence visual perception. The results for DS from both the Spatial Task and Transformation Task, along with Experiment 2, suggest that the spatial imagery processes result in the same colour effect. Importantly, with the current tasks the inducer was not externally presented, as it had been in the Smilek et al study. However, the current results suggest that spatial imagery processes can elicit a synaesthetic concurrent in the absence of this external presentation. Subsequently, this suggests that the visual processing of the grapheme-form is not always required for DS, as the spatial imagery processes are not thought to use the early visual processes. Instead, they are thought to rely on spatial processes within the parietal cortex.

A colour effect was also found for ZV in the Spatial Task. However, unlike the Resolution and Object Tasks, with the Spatial Task the opponent condition was found to be significantly faster than both the 'no colour' and congruent conditions. Yet unlike DS, her performance on the Spatial Task did not go in the same direction as her performance on the Transformation Task. This could suggest a divergence between the processes used with these two tasks and their subsequent interaction with the synaesthetic processes. Having only behavioural data available it would be difficult to draw a definite conclusion, but a possible explanation for this colour effect comes from a subjective report from ZV about her task performance. After completing the Spatial Task ZV commented that she had found trials with certain graphemes especially difficult as these graphemes had the same synaesthetic concurrent as each other. One such example concerns the graphemes "A" and "C" that were in the same familiarisation box, which for ZV both have the same yellow concurrent. Consequently, for the trials that required ZV to recall the spatial location of "A", she may have recalled a yellow colour in both the position of "A" and the position of "C", but not recall which was which. Subjectively therefore she was using her synaesthetic colours to aid her spatial imagery, but due to the selection of graphemes for this task it was not always a helpful strategy. This account can also be used to explain why, of the four colour conditions, she was fastest in the opponent condition. In the opponent condition the background colour was not the same as any of her synaesthetic colours and so there was no confusion caused by the colour presented on the screen. Conversely, in both the congruent and incongruent conditions the colour could lead ZV to think of two possible graphemes, rather than just the one she was trying to visualise for the current trial. The results from the Spatial Task for ZV therefore illustrate an interesting issue of how synaesthetes might strategically use their synaesthetic colours in tasks such as those used in the current study.

In summary, the findings from the Spatial Task show that for three of the synaesthetes background colour was not found to reliably affect task performance, and so this did not support the prediction that had been based on their performances in Experiment 2 and 3. Interestingly DS did show a significant effect of colour, and this was the same as he showed with the Transformation Task and in Experiment 2, and they both had spatial rate-limiting imagery processes. On the other hand, ZV showed a significant effect of colour that did not resemble her performance on the Transformation Task or Object Task, although it may be possible to explain her performance by her use of a task-specific strategy.

Visual Task Results and Discussion

Table 5.5a shows the Visual Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can be seen that the direction of the colour effect was the same for both the incongruent and opponent conditions within an individual synaesthete, but that the direction varied between synaesthetes. For ZV the effect of colour approached significance ($F(3, 82) = 2.4$, $p=.07$, $\eta^2 = .08$), and comparing just the incongruent and congruent conditions showed a significant difference, (t(40) = 2.45, p = .019, *d* = 0.76), with the incongruent condition being slower. A significant effect of colour was not found for RW (F(3, 81) = 2.22, p=.09, η^2 = .08), for (VE, F(3, 75) = 0.12, p = .95, η^2 = .005), or for DS (F(3, 84) = 0.28, p=.84, η^2 = .01). For KD, the assumption of homogeneity of variance was again found to be violated (F(3, 83) = 4.8, p = .004) and therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was not found (F(3, 70) = 0.79, p = .51, η^2 = .03). However, for RW directly comparing the congruent condition with the incongruent condition found the congruent condition to be significantly faster (t(39) = 1.79, p = .041 (one-tailed), *d* = 0.56). Overall therefore, there was some support for the hypothesis that background colour would affect task performance when the grapheme was visually presented.

Table 5.5a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Visual Task in Experiment 4

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
RW	1528 (388)	1750 (409)	1602 (316)	1481 (339)	-222	-74
VE	1521 (377)	1592 (410)	1540 (402)	1538 (436)	-71	-19
KD	1236 (444)	1099 (224)	1113 (361)	1120 (290)	137	123
DS	2001 (813)	2067 (835)	2112 (805)	1906 (717)	-66	-111
ZV	2669 (902)	3307 (775)	2892 (815)	2728 (882)	-638	-223

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed across the colour conditions (see Table 5.5b). Of particular interest for the current analysis is the ER for ZV and RW. Importantly for ZV this shows that there was no difference between the ERs for the congruent and incongruent conditions. Therefore the interpretation of the RT analysis for ZV was not compromised by a speed-accuracy trade-off. Also, RW had very similar ERs in both the congruent and incongruent conditions. Additionally, there were no significant correlations between ERs and RTs for KD, DS and ZV (all *p*s > .05) indicating a general absence of speed-accuracy trade-offs for these synaesthetes. For RW and VE a significant correlation between ER and RT was found; for RW this was a positive correlation reflecting the absence of a speed-accuracy trade-off (r = .98, p = .019), whereas for VE it was a negative correlation reflecting a possible speed-accuracy trade-off (r = -.96, p = .039).

Table 5.5b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Visual Task in Experiment 4

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
RW	7	1	3	2	1
VE	11	3	2	3	3
KD	9	1	2	1	5
DS	7	2	2	1	2
ZV	8	2	2	3	1

Visual Task Discussion: The Visual Task did not involve mental imagery processes as the grapheme was visually displayed within each trial. The same graphemes were used in the Visual Task as used in the Resolution, Transformation and Spatial Tasks, but importantly without each of the respective rate-limiting imagery processes. Although imagery processes were not required, since mental imagery and visual perception are thought to share a high percentage of neural substrates, it was anticipated that the Visual Task would show a similar colour effect to some of the imagery tasks. In particular, it was expected that synaesthetes would show a similar pattern of results with the Visual Task as they had been expected to show with the Resolution Task, as this imagery task was thought likely to utilise some of the same early visual processes as used in visual perception. As the hypotheses for the Resolution Task had been based on the findings Experiment 1, it was also predicted that in the Visual Task RW, DS and VE would show a significant effect of colour, with the congruent trials being faster than the incongruent for RW and DS, and vice versa for VE. As predicted, RW was found to be significantly faster in the congruent condition than the incongruent. Also, ZV's performance on the Visual Task was found to be affected by the background colour, with the incongruent condition being significantly slower than the congruent condition. However, DS and VE did not show the expected significant effect of colour (although the direction of the effect was as predicted for DS). It is therefore important to discuss RW's performance in relation to the imagery tasks within this study and Experiment 1, ZV's unpredicted colour effect, and potential explanations for the lack of a significant colour effect for DS and VE.

Importantly, as predicted RW was found to be significantly faster in the congruent condition than the incongruent. Therefore, when the inducer was externally presented in a visual form, the size-based decision was slower for RW when the background matched the synaesthetic concurrent of a different grapheme than when it matched the concurrent of the grapheme that was visually presented. Importantly, it was when the colour 'belonged' to another grapheme, rather than when it was in the opponent condition, that performance was particularly slowed. As noted with DS's performance on the Resolution Task, this pattern suggests that being presented with a colour usually associated with a different grapheme may bring to mind the grapheme that colour is associated with, and make it more difficult to make a decision about a different grapheme. This bi-directional interference has been shown previously with tasks involving digits (Cohen Kadosh et al., 2005) and also tasks in which there were no graphemic-representations (Cohen Kadosh & Henik, 2006). The current results also support the idea that the imagery task in Experiment 1 used many of the same processes as used in the current Visual Task, as when the grapheme was both visually presented (current Visual Task) and internally generated (imagery task in Experiment 1) RW's performance was slower in the incongruent condition. As mental imagery studies with the non-synaesthete population have found that approximately 90% of the same brain areas are activated when participants make a judgement about mental images or visually presented pictures of the same stimuli (Ganis et al, 2004), it is not surprising that colour was found to affect RW's performance when making a judgement about a visually presented grapheme, or a grapheme within a mental image.

Interestingly however, the results from the current Visual Task did not reflect the pattern of results found for RW with the Resolution Task, in which she was significantly faster with the incongruent trials. It was expected that the Resolution Task in particular would utilise similar processes as the Visual Task and so it is interesting that the observed colour effects for these tasks went in opposing directions for RW. If almost the same neural processes are involved in both tasks then one would expect the colour effects, although maybe varying in strength, to be similar in overall direction of effect. A possible explanation for this difference in colour relates to the absence of the colour-free ‘image-forming’ stage in the current tasks. The ‘image-forming’ stage was absent from both the Visual and Resolution Task, but it actually was not needed with the Visual Task, as the grapheme was visually presented from the onset of each trial. Consequently, in the Visual Task RW was essentially starting each trial at the start of the ‘decision-making’ stage used in Experiment 1 (see Figure 2.1), with either the image of the grapheme formed (imagery task), or the grapheme visually presented (Visual Task). The colour effect found in Experiment 1 therefore seems to represent the effect that colour had on the actual decision-making process, as it also had the same effect in the Visual Task, which only required the decision-making process. However, with the Resolution Task the colour effect could have been from either the “image-forming” or “decision-making” stage of the trial, because colour was introduced at the start of each trial. As there was a difference in effect between the Resolution Task and Visual Task, it could therefore be predicted that for RW the effect of colour found with the Resolution Task represented the effect on the “image forming” stage. If it had been from the “decision-making” stage then one would expect colour to be the same help or hindrance on task performance as found with the Visual Task and earlier imagery task in Experiment 1.

In the Visual Task ZV was also found to be slowest in the incongruent condition, and significantly slower than she was in the congruent condition. Therefore, when visually presented with a grapheme on a coloured background that matched the synaesthetic concurrent usually associated with a different grapheme, the size-based decision was slower. This suggests again that the background colour may be bringing to mind the grapheme that would usually be associated with that colour, illustrating the bi-directional nature of synaesthesia. Importantly this was the same pattern of results as found for ZV in the Object Task where there was also a significant effect of colour. This therefore suggests that the interaction between the synaesthetic concurrent and ‘real’ colour had a similar effect on task performance in both the Object Task, when the grapheme was an internally generated mental image, and the Visual Task, when the grapheme was externally presented in its visual form. Plus, her results from Resolution Task showed a very similar pattern to those found with the Object and Visual Task, suggesting the use of similar processes, if lack of significance is due to lack of power. Overall therefore ZV has shown a consistent effect of colour on both imagery tasks that are thought to involve object processes and also the task that involved the visual presentation of graphemes. This again highlights the similarities between the mental imagery and visual perception processes as found by Ganis et al (2004), and the role these similar processes appear to play in the generation of a synaesthetic concurrent from both an internally generated and externally presented inducer.

Surprisingly, the Visual Task did not show a significant effect of colour on synaesthetes' performance that had been shown to be affected by colour in earlier imagery tasks. For example, the performances of DS and VE on the imagery task in Experiment 1 were both affected by the background colour, and DS was also shown to be affected by background colour with the Resolution Task. As it was hypothesised that these particular imagery tasks would use similar visual processes to the Visual Task it was expected that performance on both tasks would be alike. Importantly however the pattern of results for DS from the Visual Task did go in the predicted direction, as he did show a slight negative congruency effect. It could therefore be argued that the effect of colour simply did not reach the necessary strength to statistically affect his performance.

In summary, the findings from the Visual Task suggest that for most of the synaesthetes, when a grapheme was visually presented on the screen the background colour did not affect task performance. However, there was a statistically reliable colour effect for ZV, who was slower when the background colour matched the synaesthetic colour of a different grapheme to the one on the screen, reflecting the pattern of results observed for this synaesthete in the Object Task. RW was also slower in the incongruent condition, reflecting the results from Experiment 1, when the grapheme was not externally presented, but instead internally generated as a mental image. Surprisingly, this did not reflect RW's results in the Resolution Task, which of all the imagery tasks in the current study, was expected to be most similar to the Visual Task.

Task x colour effect:

In order to explore the differences in colour effect, for individual synaesthetes the mean RT for each colour condition was also compared across all tasks. For each synaesthete this was done using a two factor ANOVA with RT as the dependant variable, and Task (Object Task, Resolution Task, Transformation Task, Spatial Task and Visual Task) and Colour (congruent, incongruent and ‘no colour) as the two independent variables.

For RW a main effect of task was found (F(4, 349) = 38.6, p <.01, η^2 = .31), but no main effect of colour (F(3, 349) = 0.67, p = .57, η^2 = .01). A significant interaction between task and colour was also found (F(12, 349) = 1.92, p = .03, η^2 = .06). Post-hoc tests showed that with the main effect of task the Visual Task was significantly faster than the other tasks (all *p*s < .001), and that there was a significant difference between the Resolution and Spatial Tasks (p = .02), with the Resolution Task being faster than the Spatial Task. However, as shown in Figure 5.11, the interaction between task and colour shows that while in the Resolution Task the fastest condition was the incongruent condition, this was the slowest condition in both the Spatial and Transformation Tasks. This suggests a potential difference in the direction of the effect of colour between the object imagery tasks and the spatial imagery tasks.

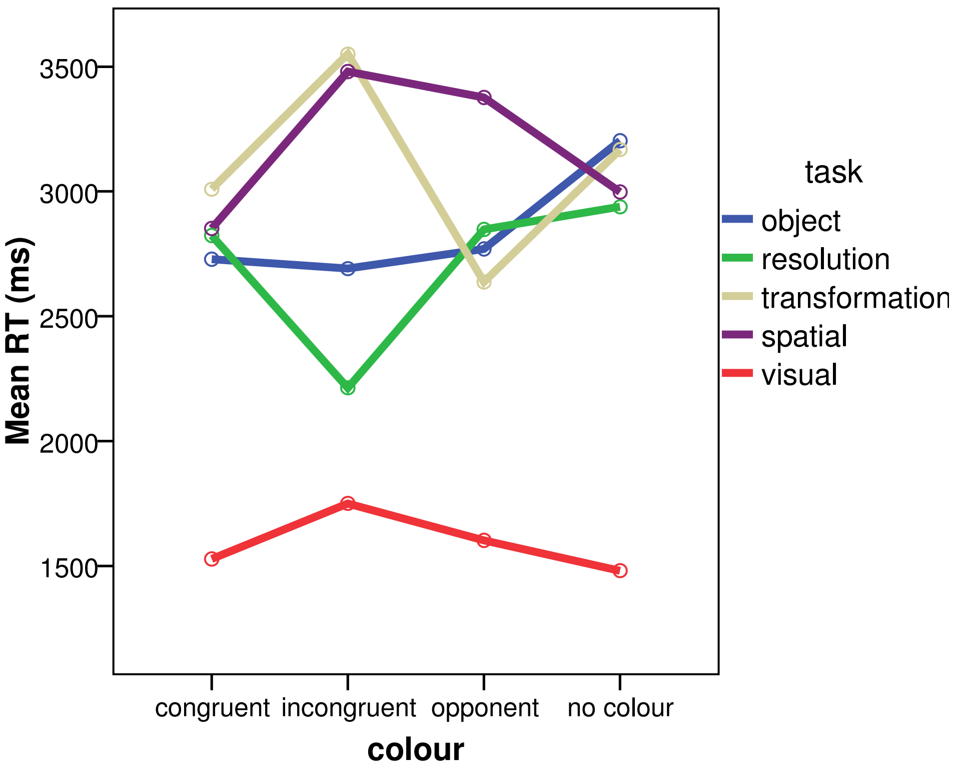


Fig 5.11: Mean RTs for RW showing Task x Colour interaction in Experiment 4

For VE a main effect of task was found (F(4, 365) = 28.03, p <.01, η^2 = .24), but no main effect of colour (F(3, 365) = 0.7, p = .56, η^2 = .01). The interaction between task and colour was also not significant (F(12, 365) = 1.23, p = .26, η^2 = .04). Post hoc tests showed that for the main effect of task the Visual Task was significantly faster than the other tasks (all *p*s < .001) and that there was a significant difference between the Resolution Task and both the Transformation Task and Spatial Task (p = .006 and .05 respectively), with the Resolution task being significantly faster than both.

For KD a main effect of task was found (F(4, 358) = 63.8, p <.01, η^2 = .42), but no main effect of colour (F(3, 358) = 63.8, p <.01, η^2 = .004). The interaction between task and colour was also not significant (F(12, 358) = 1.23, p = .26, η^2 = .04). Post hoc tests showed that for the main effect of task the Visual Task was significantly faster than the other tasks (all *p*s < .001) and the Spatial Task was significantly slower than the other tasks (all *p*s < .001). There was also a significant difference between the Object and Transformation Tasks (p = .002), with the Transformation Task being the fastest of the two.

For DS a main effect of task was found (F(4, 378) = 25.72, p <.01, η^2 = .21), and a main effect of colour (F(3, 378) = 3.83, p =.01, η^2 = .03). A significant interaction was found between task and colour (F(12, 378) = 2.35, p = <.001, η^2 = .07). For the main effect of task, post hoc tests showed that this was driven by a faster response to the Visual Task than the other tasks (all *p*s < .001). For the main effect of colour the congruent condition was found to be significantly slower than the 'no colour' condition (p = .005), which was the fastest condition. However, the interaction between task and colour, as shown in Figure 5.12, suggests that while the congruent condition was the slowest for the Transformation and Spatial Tasks, this was not the case for the Object and Resolution Tasks. This again suggests a divergence between the tasks using object imagery processes and those using spatial imagery processes.

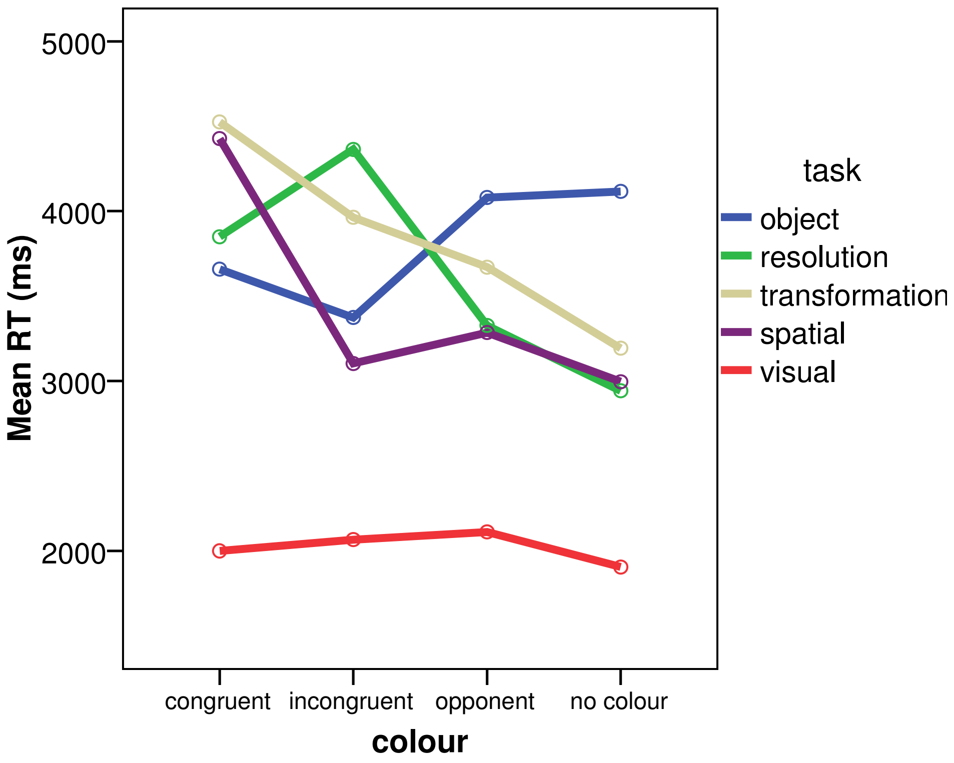


Fig 5.12: Mean RTs for DS showing Task x Colour interaction in Experiment 4

For ZV a main effect of task was found (F(4, 354) = 16.23, p <.01, η^2 = .16) and an main effect of colour that approached significance (F(3, 354) = 2.33, p =.07, η^2 = .02). A significant interaction was found between task and colour (F(12, 354) = 2.53, p <.01, η^2 = .08). Post hoc tests showed that the main effect of task was driven by a faster response in the Visual Task than the other tasks (all *p*s < .001), and also the Transformation Task was significantly slower than the other tasks (all *p*s < .02). For the main effect of colour, the incongruent condition was significantly slower than the opponent condition (p = .045). However, there was an interaction between task and colour, and as shown in Figure 5.13, while the Object, Resolution and Visual Tasks had a very similar pattern of results, with the incongruent condition being the slowest condition, in the Spatial Task, the congruent condition was the slowest of the coloured conditions. It is also interesting to see that in the opponent condition of the Spatial Task ZV was faster than she was in the incongruent condition of the Visual Task (which was generally the fastest of the tasks as mental imagery was not required).

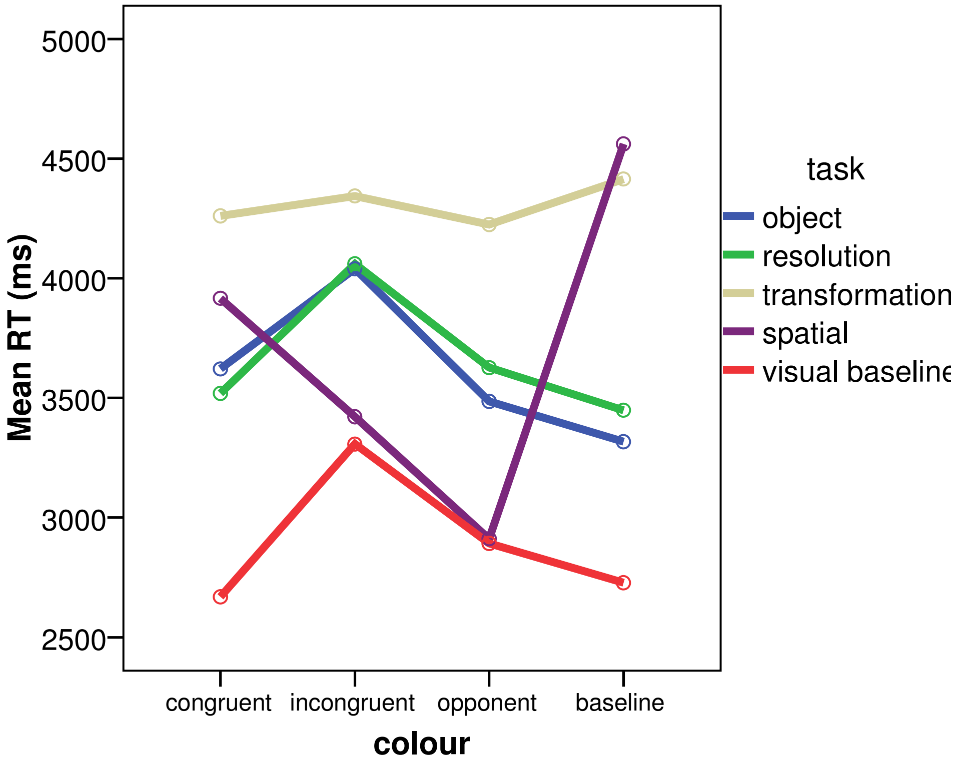


Fig 5.13: Mean RTs for ZV showing Task x Colour interaction in Experiment 4

In summary, all of the synaesthetes were fastest in the Visual Task, which would be expected as this task did not involve the use of imagery. Previous studies using a visual task and imagery task have also found the visual task to be the faster of the two (Borst & Kosslyn, 2008). By considering the possible interactions between the different tasks and different colour conditions, three synaesthetes showed very interesting interactions. Due to the number of variables at play, interpretation can be difficult. However, the patterns of these interactions provide some initial support for the idea that the effect of the interaction between the colour of the synaesthetic concurrent and 'real' background colour varies between tasks that purportedly use different imagery processes. For RW, DS, and ZV the tasks that were thought to use spatial imagery processes (the Transformation and Spatial Tasks) showed a different pattern of results than those that used object imagery processes (either the Resolution or Object Tasks).

5.4: Experiment 4 General Discussion

Experiment 4 has used a modified version of the Visual Cognition Battery (Kosslyn, Shephard, Burrage, & Thompson, 2006) to explore the role of purportedly different imagery processes in the generation of a synaesthetic concurrent from a mental image of an inducer. Synaesthetes completed five tasks in total; two required object imagery processes, two required spatial imagery processes, while the last used externally presented graphemes. By manipulating the background colour the imagery tasks were performed against, the results show that background colour had an effect on performance for some synaesthetes on some of the tasks. Specifically, RW showed a reliable colour effect on the Resolution Task and Visual Task, DS showed a colour effect on the Resolution Task, Transformation Task and Spatial Task, and ZV showed a colour effect on the Object Task, Spatial Task and Visual Task. Importantly, the current results have therefore expanded on the findings from Experiment 1, as the results suggest that the interaction between the concurrent elicited from a mental image of the grapheme and the ‘real’ background colour can affect task performance for some synaesthetes in some of the tasks. An initial conclusion therefore is that these results provide further support for the idea that a synaesthetic concurrent can be elicited without the external presentation of the inducer. Additionally, by using a modified version of the Visual Cognition Battery (Kosslyn, Shephard, Burrage, & Thompson, 2006), the results have expanded on these earlier findings, as they highlight the diverse roles the purportedly different imagery processes may play in the generation of the concurrent. As the tasks within the battery were largely comparable, except for their task-specific rate-limiting imagery processes, the finding that individual synaesthetes showed different colour-effects between the tasks suggests that these distinct imagery processes potentially modulated the effect that the subsequent concurrent/'real' colour interaction had on task performance.

As object imagery and spatial imagery are thought to use two different visual pathways, it was predicted that background colour would have a distinct effect on the tasks that used each type of process, based on the results of Experiments 1 to 4. For the synaesthetes who had shown a colour effect in Experiment 1, colour was expected to affect synaesthetes' performance on the tasks using object imagery processes. For the synaesthetes who had shown an effect of colour with the mental rotation tasks in either Experiment 2 or 3, colour was expected to affect their performance on the tasks using spatial imagery processes. The results suggest that while for some synaesthetes there was an interaction between task and colour, with some interesting patterns emerging, only some of the initial predictions were supported for each of the synaesthetes. For example, DS showed the predicted colour effect in both the Transformation and Spatial Task. Consequently, based on these and the earlier findings it is not possible to argue that the generation of a synaesthetic concurrent from a mental image of an inducer requires the explicit visual processing of the grapheme form, as these spatial processes were not likely to use the early visual areas. Interestingly, his results provide further support for the idea that the different imagery processes could result in a different form of 'colour effect' for some synaesthetes. This is because the direction of the effect for DS found with the Transformation and Spatial Task was actually in the opposite direction to the effect he showed with the Resolution Task which used an object imagery process. This is further supported by his performance on the imagery tasks in the earlier experiments, as the colour effect found for DS with the imagery task in Experiment 1, which can be seen to utilise object imagery processes, went in the same direction as the Resolution Task. Furthermore, his performance on the mental rotation tasks in Experiments 2-3, was similarly affected by colour as it was in with the current spatial-imagery processes. This suggests therefore that, for some synaesthetes a concurrent can be elicited from imagery tasks involving either object or spatial processes, but the way the concurrent interacts with the 'real' colour processing may differ between these processes. DS's performance with the object-based tasks suggests that the background colour was in some way bringing to mind the grapheme usually associated with the background colour, as he was slower in the incongruent condition with the Resolution Task and Experiment 1. As it was the incongruent condition, and not the opponent condition, in which he was particularly slowed, this points towards a possible bi-directionality with his synaesthesia. In contrast, the congruent colour impeded his performance on the tasks purportedly using spatial imagery processes, suggesting that when using spatial imagery processes whilst looking at the congruent coloured background, there was a kind of 'camouflage effect' as found by Smilek et al (2001), with their visual search task. The performance of DS across the tasks therefore highlights the complexity of the processes involved in the generation of the synaesthetic concurrent, and how this is affected by the demands of the imagery task.

Although a concurrent can seemingly be elicited from both object and spatial imagery processes, the results from Experiment 4 also suggest the potential importance that the visual processing of the grapheme form may play for some synaesthetes with some of the tasks. For example, as RW and DS both showed a strong effect of colour in Experiment 1 it was hypothesised that they would both show a similar colour effect in the Object and Resolution Tasks. However, they were found to show a significant effect of colour in the Resolution Task but not the Object Task. The key difference between these tasks was the rate-limiting imagery process, and so it can be argued that the high-level of resolution required for the images in the Resolution Task was a determining factor in the subsequent generation of their synaesthetic concurrents. The results suggest that for these synaesthetes the image of the inducer needed to have a high level of visual detail in order for the processing of the concurrent to interact with the processing of the ‘real’ background colour, and subsequently affect task performance. Previous imagery research has found that mental images with high level of resolution are more likely to show activation in retinotopically organised areas of early visual cortex (Kosslyn & Thompson, 2003). If it was the case, as suggested by this imagery research, that the images required for the Resolution Task activated these early visual areas, whereas the images in the Object Task did not, then it would seem that this early visual processing of the inducers is important for the internally generated inducer to elicit a concurrent. Therefore, when the task required the use of object-imagery processes, the level of the visual processing required did seem to affect the subsequent generation of the synaesthetic concurrent. However, it is important to note that this was not the case for all synaesthetes. For example, ZV showed a statistically reliable effect of colour with the Object Task, but this effect did not reach the standard level of significance with the Resolution Task. This again highlights the importance of individual differences with regards to the way synaesthesia and mental imagery interact, and the complexity of the processes involved.

Comparison of the Incongruent and Opponent Conditions

An important addition to Experiment 4 was the opponent colour condition. The opponent colour condition had not been used in Experiments 1-3, and was introduced in to Experiment 4 following the publication of a visual Stroop study that suggested early visual processing stages involved in real colour perception were also used in the perception of synaesthetic colours (Nikolić, Lichti, & Singer, 2007). From inspecting the results across the tasks in Experiment 4 it was clear that the opponent and incongruent conditions should be considered as separate conditions, as it is apparent that the two types of incongruent colour could have quite contrasting effects on task performance. However, from the overall results it would appear that the opponent condition did not result in the predicted larger congruency effect across the tasks for the synaesthetes, as found by Nikolić et al with the externally presented graphemes. Therefore direct support was not found for the idea that the concurrent elicited from a mental image of a grapheme would be processed at the early colour processing stages. However, the inclusion of the opponent condition was a very useful addition to Experiment 4 as it showed how, frequently, the colour effect found for individual synaesthetes involved the visualisation of a grapheme whilst looking at a colour usually experienced with another grapheme, rather than the opponent condition. As the colours used in the opponent condition were essentially colours that the synaesthete did not associate with a grapheme the inclusion of this condition illustrated how it was not merely the “wrong” colour that could help or hinder task completion but rather it was specifically a colour that ‘belonged’ to another grapheme from that synaesthete’s point of view. This is extremely useful in adding further understanding to the synaesthetic experiences induced from a mental image of a grapheme, as it could be used to suggest that the “synaesthetic colour” to “background colour” interference was happening at a semantic level rather than at the early processing stages of colour perception. Potentially it was the synaesthete’s life-long knowledge about a grapheme that caused the colour effect (e.g. if the concurrent for ‘F’ was green, and the background was blue, which was usually associated with the grapheme ‘G’). The possible implications of this are discussed further in Chapter 7.

Summary of Experiment 4

Experiment 4 aimed to explore the determinants of a synaesthetic concurrent resulting from different mental imagery processes. Individual differences have again been found to be important, as it can be concluded that for some of the synaesthetes, certain imagery processes were found to generate a synaesthetic concurrent. For some of the synaesthetes there appeared to be a divergence in the effect of colour for two different types of task. As shown by the results of DS and RW in particular, the tasks that used object imagery processes had one effect, while the tasks that used spatial processes had a different effect. Additionally, the introduction of the new colour condition also produced some interesting findings, illustrating how the interaction between the background colour and the synaesthetic concurrent from the grapheme being visualised is augmented when the background colour ‘belongs’ to another grapheme, rather than simply being just the wrong colour. However, some of the predictions were not found to be supported, and so further testing is required on the basis of possible explanations of these unexpected findings. First, to explore the possible impact of practice effects as discussed in relation to VE’s performance, “naïve” synaesthetes who have not previously taken part in synaesthesia research were recruited to complete the tasks from the current study. Second, to see whether the omission of a colour-free image generation stage from the trials in the current study influenced the subsequent synaesthetic experience, as discussed in relation to the unexpected effects found, a subset of the synaesthetes who took part were recruited to take part in a modified version, in which the trials had distinct image generation stages and decision making stages (see Experiment 5a and 5b).

Chapter 6: Further exploring the determinants of a synaesthetic concurrent from different mental imagery processes

(Experiments 5a and 5b)

6.1: Experiment 5a and 5b Introduction

The battery of tasks in Experiment 4 was used to systematically explore the possible roles that object and spatial imagery processes play in the generation of a concurrent from a mental image of a grapheme. Although there was some support for a difference in effect for these two types of imagery processes, the results of Experiment 4 did not provide support for the predictions for all synaesthetes. For example, VE had shown a clear colour effect with the imagery task in Experiment 1, but had not shown the expected effect of colour in the similar tasks using object imagery processes in Experiment 4. Additionally, although colour had reliably affected RW's performance on the Resolution Task in Experiment 4, it had been in the opposite direction to that predicted by her performance in Experiment 1. Possible explanations were suggested for these inconsistencies, and Experiments 5a and 5b were designed in order to further explore these issues.

6.2: Experiment 5a Outline

The synaesthetes in Experiment 4 had all taken part in the previous three experiments and so it was possible that some may have been affected by ‘practice effects’. This was because the tasks in the previous experiments had all been very similar in overall design, i.e. the background colour was manipulated so that it was congruent or incongruent with the grapheme being visualised. VE, for example, had taken part in studies with other research groups, in addition to the studies presented here. Consequently, a significant colour effect may not have been found for her with the tasks in Experiment 4 due to her previous experience with the colour manipulation paradigm being used. The consequences of over exposure to the colour manipulation paradigm, as used by many synaesthesia researchers, has not been explored before and so it is not clear whether this would result in a ‘weakening’ of the congruency effect. Such a finding would suggest that synaesthetes can develop strategies to overcome what is considered to be an ‘automatic’ process.

Experiment 5a therefore used the same version of the Modified Visual Cognition Battery as used in Experiment 4, but with a set of synaesthetes who had not previously taken part in any synaesthesia research. Although it was not possible to predict the direction of the effects for the individual synaesthetes, it was hypothesised that each of the naïve synaesthetes would show significant colour effects in the tasks, based on the findings of the earlier studies in Experiments 1 to 3. This is based on the premise that the lack of support for the expected results in Experiment 4 were due to practice effects diminishing the impact of the colour manipulation paradigm. Stronger effects of colour would also be expected across the tasks with the naïve group of synaesthetes, compared to the original synaesthetes, if practice effects had been a mitigating factor in Experiment 4.

6.3: Experiment 5a Method

Participants

In total three female grapheme-colour synaesthetes were recruited to take part in the current study. These synaesthetes had not taken part in any previous experimental studies exploring synaesthesia. SLB and ES had English as their first language, while AS had German as her first language but was fluent in English (she was attending university in the UK). They were all in good mental health according to self report, and had normal or corrected-to-normal visual acuity. Their age range was 20-57 years. The internal reliability of their synaesthetic colour responses, as measured by the modified Test of Genuineness, was 89% for ES and 100% for AS. SLB was unavailable to complete the second stage of the ToG, and therefore her scores from the online “Synesthesia Battery” are used (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). In all tests of the Synesthesia Battery SLB scored within the required threshold to be considered a synaesthete; her score for the grapheme-colour picker test was 0.81 (under 1.0 is considered a synaesthete) and her accuracy on the speeded-congruency test was 86.1% (over 85% is considered a synaesthete). The synaesthetes also completed the VVIQ. Table 6.1 summaries the participant characteristics.

Table 6.1: Participant demographics for synaesthetes in Experiment 5a, including each synaesthete's Test of Genuineness (modified) test-retest reliability percentage (ToG %), and each synaesthete's total score on the Vividness of Visual Imagery Quota (VVIQ; Marks, 1973)

Synaesthete	Gender	Age	*ToG **%**	VVIQ Total
SLB	female	51	-	51
AS	female	20	100%	46
ES	female	57	89%	78

Materials and Procedure

The same materials and procedure were used as those used in Experiment 4. As before, prior to completing the tasks the participants provided details of the colours experienced with each grapheme, and these details were used to create a set of congruent, incongruent and opponent background colours for each individual synaesthete. Participants had written instructions for each task (see Appendix D), and first completed the familiarisation stage followed by the five trial tasks in the same order as before; Object Task, Resolution Task, Transformation Task, Spatial Task and Visual Task.

6.4: Experiment 5a Results

The same method of analysis was used for the current study as used with the tasks from Experiment 4; the standard congruency effect (CE-S) was calculated by subtracting the mean RT for the incongruent trials from the mean RT for the congruent trials, and the 'opponent' congruency effect (CE-O) was calculated by subtracting the mean RT for the opponent trials from the mean RT for the congruent trials. For all tasks the mean RT for each condition was calculated using trials answered correctly and trials that were treated as outliers (using stem and leaf procedures from SPSS package 10.1) were removed independently for all conditions. This procedure resulted in 3%, 5% and 7% of trials being removed for SLB, AS and ES respectively, across the five tasks.

Object Task:

Response time analysis: Table 6.2a shows the Object Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can be seen that the direction of the effect of colour on RT varied across the synaesthetes. Although the variance between conditions seems quite large for each synaesthete, the standard deviations suggest that there was also a large amount of within-condition variance. One-way ANOVAs did not show a significant colour effect for any of the synaesthetes: for SLB, the assumption of homogeneity of variance was found to be violated ($F(3, 57) = 7.78$, $p < .001$) and therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was not found ($F(3, 22) = 0.73$, $p = .55$, $\eta^2 = .04$); for AS, the assumption of homogeneity of variance was also found to be violated ($F(3, 62) = 4.58$, $p = .006$) and therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was not found ($F(3, 39) = 1.15$, $p=.34$, $\eta^2 = .06$) and for ES a significant effect of colour was not found ($F(3, 77) = 0.63$, $p=.6$, $\eta^2 = .03$).

Table 6.2a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for 'naïve' synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Object Task in Experiment 5a.

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
SLB	3780 (980)	3494 (547)	4292 (2202)	3769 (1128)	286	-512
AS	7479 (3314)	8269 (5417)	6068 (2020)	8032 (3467)	-790	1411
ES	3766 (1183)	4131 (1854)	4108 (1885)	3534 (1475)	-365	-342

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed across the colour conditions (see Table 6.2b). Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all ps > .1) indicating a general absence of speed-accuracy trade-offs.

Table 6.2b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Object Task in Experiment 5a

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
SLB	33	7	9	12	5
AS	23	7	8	4	4
ES	8	2	1	3	2

Resolution task:

Response time analysis: Table 6.3a shows the Resolution Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can be seen that both the between condition and within condition variance for each synaesthete was again large, and while for SLB and AS the congruent condition was the slowest, for ES it was the fastest. One-way ANOVA however did not show significant colour effects for SLB ($F(3, 69) = 1.28$, $p = .29$, $\eta^2 = .05$) or for AS ($F(3, 65) = 0.42$, $p = .74$, $\eta^2 = .02$). For ES, the assumption of homogeneity of variance was found to be violated ($F(3, 71) = 4.35$, $p = .007$) and therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was not found ($F(3, 54) = 0.83$, $p = .48$, $\eta^2 = .03$).

Table 6.3a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for 'naïve' synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Resolution Task in Experiment 5a

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
SLB	4803 (2599)	3748 (1420)	3695 (1472)	4171 (1944)	1054	1108
AS	6234 (3335)	5509 (2813)	5179 (2107)	5948 (3026)	725	1055
ES	2812 (987)	3066 (1067)	2922 (941)	3408 (1724)	-254	-110

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed slightly across the colour conditions (see Table 6.3b). Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all ps > .1) indicating a general absence of speed-accuracy trade-offs.

Table 6.3b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Resolution Task in Experiment 5a

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
SLB	22	6	5	6	5
AS	22	8	4	6	4
ES	13	4	2	4	3

Transformation task:

Response time analysis: Table 6.4a shows the Transformation Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can be seen that the size and direction of the colour effect varied across synaesthetes. A one-way ANOVA for ES suggested a trend in the effect of colour ($F(3, 63) = 2.15$, $p = .1$, $\eta^2 = .09$) with post hoc tests suggesting a difference between the incongruent and 'no colour' conditions ($p=.2$) with the incongruent condition being slower than the 'no colour' condition. One-way ANOVAs did not show a significant effect of colour for AS ($F(3, 62) = 1.8$, $p=.15$, $\eta^2 = .08$) and for SLB, the assumption of homogeneity of variance was found to be violated ($F(3, 50) = 2.87$, $p = .045$) and therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was not found ($F(3, 40) = 0.75$, $p = .53$, $\eta^2 = .04$). However as the difference between the congruent and opponent conditions was much larger than previous tasks further analysis was conducted which showed that for AS comparing the mean RT for the congruent condition with just the mean RT for the opponent condition did show a significant effect of colour (t(31) = 2.62, p = .014, *d* = 0.93), with the opponent condition being the faster of the two.

Table 6.4a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for 'naïve' synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Transformation Task in Experiment 5a

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
SLB	4303 (946)	5273 (1974)	4954 (2117)	5174 (1839)	-970	-651
AS	5876 (1814)	5508 (2609)	4422 (1321)	6197 (3064)	368	1454
ES	4250 (1587)	4503(1336)	3623 (892)	3533 (1416)	-253	627

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed slightly across the colour conditions, although for AS there was no difference across conditions (see Table 6.4b). Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all ps > .1) indicating a general absence of speed-accuracy trade-offs.

Table 6.4b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Transformation Task in Experiment 5a

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
SLB	40	10	8	13	9
AS	24	6	6	6	6
ES	24	6	7	5	6

Spatial task:

Response time analysis: Table 6.5a shows the Spatial Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can be seen that the direction and size of the colour effect varied across synaesthetes. For ES, the assumption of homogeneity of variance was found to be violated (F(3, 75) = 5.52, p = .002) and therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was found (F(3, 49) = 3.35, p = .026, η^2 = .11). Post-hoc tests revealed that there was a significant difference between the incongruent and opponent conditions (p=.03) with the opponent condition being faster than the incongruent condition. Furthermore, due to the relatively large difference between the congruent and opponent conditions further analysis was conducted which showed a close to significant difference between the mean RTs for the congruent and opponent conditions (t(39) = 1.86, p = .07, *d* = 0.6, equal variances not assumed), with the opponent condition being the faster of the two. One-way ANOVAs did not show a significant effect of colour in the Spatial Task for SLB (F(3, 76) = 0.87, p = .46, η^2 = .03) and for AS, the assumption of homogeneity of variance was also found to be violated (F(3, 77) = 2.9, p = .04) and therefore the Brown-Forsyth F ratio is reported, and a significant effect of colour was not found (F(3, 71) = 0.56, p = .65, η^2 = .02).

Table 6.5a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for 'naïve' synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Spatial Task in Experiment 5a

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
SLB	3804 (1873)	4565 (2174)	4623 (1994)	4023 (1798)	-761	-819
AS	3613 (1924)	3458 (1510)	3078 (1243)	3601 (1235)	155	535
ES	3458 (1253)	4078 (1938)	2889 (642)	3126 (841)	-620	569

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed across the colour conditions (see Table 6.5b). Of particular interest for this task is ES's ER, and importantly there was little difference between the incongruent and opponent conditions, suggesting that the interpretation of the RT results is not affected by a speed-accuracy trade-off. Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all ps > .1) indicating a general absence of speed-accuracy trade-offs.

Table 6.5b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Spatial Task in Experiment 5a

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
SLB	15	2	5	4	4
AS	13	2	3	3	5
ES	10	2	1	2	5

Visual Task:

Response time analysis: Table 6.6a shows the Visual Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can be seen that there was a lot less difference in RT between the colour conditions. One-way ANOVAs did not show a significant effect of colour in the Visual Task for SLB ($F(3, 77) = 0.96$, $p = .42$, $\eta^2 = .02$), for AS ($F(3, 76) = 0.6$, $p = .62$, $\eta^2 = .02$), or for ES ($F(3, 81) = 0.31$, $p = .82$, $\eta^2 = .01$).

Table 6.6a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for ‘naïve’ synaesthetes as a function of colour condition (congruent, incongruent, opponent and ‘no colour’) in the Visual Task in Experiment 5a

	Colour condition				Congruency Effect	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
SLB	2624 (736)	2644 (780)	2548 (662)	2313 (424)	-20	76
AS	2101 (633)	2101 (679)	2032 (507)	1884 (536)	0	-69
ES	2778 (777)	2595 (826)	2764 (837)	2593 (950)	183	14

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed slightly across the colour conditions for SLB and AS, whereas for ES it did not change across the conditions (see Table 6.6b). Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all ps > .1) indicating a general absence of speed-accuracy trade-offs.

Table 6.6b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the Visual Task in Experiment 5a

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
SLB	9	3	2	2	2
AS	13	2	4	4	3
ES	4	1	1	1	1

Task x colour interaction:

As used in Chapter 5, for each synaesthete a two factor ANOVA with Task and Colour as the two independent variables was used to explore the effect of colour across the tasks. For SLB a main effect of task was found ($F(4, 329) = 21.43$, $p <.01$, $\eta^2 = .21$) no main effect of colour ($F(3, 329) = 0.16$, $p = .93$, $\eta^2 = .001$), and no significant interaction between task and colour ($F(12, 329) = 1.17$, $p = .3$, $\eta^2 = .04$). Post hoc tests showed that the Visual Task was significantly faster than the other tasks (all *p*s < .01) and the Transformation Task was significantly slower than the Object and Resolution tasks (all *p*s < .05). For ES a main effect of task was found ($F(4, 367) = 14.1$, $p <.01$, $\eta^2 = .13$), an effect of colour that approached significance ($F(3, 367) = 2.38$, $p =.07$, $\eta^2 = .02$), and no significant interaction between task and colour ($F(12, 367) = 1.28$, $p = .23$, $\eta^2 = .04$). For the effect of task post hoc tests showed that the Visual Task was significantly faster than the Object, Transformation, and Spatial tasks (all *p*s < .01) and the Resolution Task was also significantly faster than the Object and Transformation tasks (all *p*s < .01). For the effect of colour the incongruent condition was (almost) significantly slower than the 'no colour' condition (p =

.08). Finally, for AS a main effect of task was found ($F(4, 342) = 58.31, p <.001, \eta^2 = .4$), a main effect of colour ($F(3, 342) = 3.22, p =.023, \eta^2 = .03$), and no significant interaction between task and colour ($F(12, 342) = 0.64, p = .81, \eta^2 = .02$). For the main effect of task post hoc tests showed that the Object Task was significantly slower than all of the tasks, and the Visual Task was significantly faster (all *p*s < .01). Additionally, the Spatial Task was significantly faster than the Object, Resolution and Transformation Task (all *p*s < .01). For the main effect of colour the opponent condition was significantly faster than the 'no colour' condition (p = .017). Overall, as found in Chapter 5 the Visual Task was the fastest for each of the synaesthetes, but there were no interactions between colour and task with the current experiment.

6.5 Experiment 5a Discussion

The aim of Experiment 5a was to use the same set of tasks used in Experiment 4 to explore the determinants of a synaesthetic concurrent from purportedly different mental imagery processes using 'naïve' synaesthetes. This was to explore the idea that the lack of support for some of the predictions made in Experiment 4 was due to the impact of 'practice effects' on some synaesthetes' task performances. It was therefore predicted that if this was the case, the naïve synaesthetes would show effects of colour across the various tasks in the battery. A total of three naïve synaesthetes were recruited for the Experiment 5a and importantly, none of the synaesthetes showed colour effects for the Object and Resolution Tasks, while two of the synaesthetes showed colour effects in the Transformation and Spatial Tasks. Overall therefore, the results did not provide support for the idea that the unexpected findings with the familiar synaesthetes in Experiment 4 were due to practice effects, and these results further illustrate the heterogeneous nature of the synaesthete population.

In relation to the Object Task, although the congruency effects appeared relatively larger than those found with the familiar synaesthetes, especially for AS and SLB when comparing the congruent condition with the opponent condition, these were not found to be statistically reliable. The Resolution Task produced similarly large congruency effects but without any statistically reliable effects of colour, while a significant colour effect was also not found with the Visual Task. It was expected that the Visual Task would have similar findings as the Resolution Task, as both mental imagery and visual perception share some similar neural processes (Ganis, Thompson, & Kosslyn, 2004). However, the direction of effect was not the same for the individual synaesthetes when comparing the Resolution Task and Visual Task.

With the Transformation Task the differences between the colour conditions were of a similar magnitude to those found with the other tasks, and importantly a statistically reliable effect of colour was found for two of the three synaesthetes. For AS the opponent condition was significantly faster than the congruent condition. So for AS the transformation tasks were more difficult when the background colour matched the synaesthetic concurrent from the image of the grapheme being transformed than when it was opponent. It would therefore seem that when the colour was opponent, and did not belong to another grapheme, she was significantly faster. ES also had an effect of colour that was approaching significance, with the incongruent condition slower than the ‘no colour’ condition. It is interesting that the congruent condition was also slower than both the ‘no colour’ and opponent condition, so that when the background colour belonged to a grapheme (whether congruent or incongruent) the trials took longer, but when there was a mismatch between the background colour and the grapheme being visualised in the incongruent condition she was especially slowed.

It was predicted that the effect of colour on the Spatial Task would be similar to that found with the Transformation Task. For ES there was a significant colour effect, and when the background colour was opponent to the synaesthetic colour of the grapheme being visualised ES was significantly faster than when the background colour was incongruent and congruent. Therefore again it would seem that when the background colour was one of her synaesthetic colours she was slowed, and was especially slowed when there was a mismatch. When there was no colour, or the colour did not belong to any of her graphemes (the opponent condition), her performance was not affected. This suggests that she had to think more about the trials when she was familiar with the background colour, and this was increased when the colour did not match the grapheme being used in that trial. Importantly, the incongruent condition was slowest for ES in both the Transformation and Spatial Tasks, suggesting a consistent pattern of colour effect for ES in the tasks using spatial imagery processes.

Overall therefore, results from the naïve synaesthetes in Experiment 5a have not supported the idea that the unexpected results from the familiar synaesthetes in Experiment 4 were due to practice effects. Of course this does not provide conclusive evidence of practice effects not having been a confounding variable in Experiment 4, but it makes this seem a less likely explanation. Importantly, testing the naïve synaesthetes has added further support to the importance of individual differences with regards to the determinants of a synaesthetic concurrent induced by a mental image of a grapheme. The few colour effects that were found to be statistically reliable with the naïve synaesthetes have illustrated yet more ways that the background colour can be shown to influence performance on the different imagery tasks. In particular, the consistent pattern found with ES in the tasks using spatial imagery processes suggests that distinct imagery processes can affect individual synaesthetes in different ways.

6.6: Experiment 5b Outline

One proposed explanation for Experiment 4's unexpected findings concerned the lack of a distinct 'image formation' stage within the trials in the imagery tasks. For example, the difference in trial procedure between the tasks in Experiment 4 and the imagery task procedure in Experiment 1 could be used to explain the unexpected direction of effect found with RW with the Resolution Task. In Experiment 1 participants were first presented with an empty circle on a white computer screen, and the auditory prompt indicated the grapheme to visualise (the 'image-formation' stage). They were asked to visualise the grapheme in the circle, and to make this image as clear and vivid as possible. Participants could therefore take as much time as needed before moving onto the next stage (the 'decision-making' stage). Importantly, the background colour was only changed in the 'decision-making' stage. In contrast, the 'image-formation' and 'decision-making' stage were combined in the trials in Experiment 4, as they had been in the original Visual Cognition Battery (Kosslyn, Shephard, Burrage, & Thompson, 2006). Consequently, image generation was completed against a background that was congruently or incongruently coloured, or was achromatic ('no colour' condition) with the tasks in Experiment 4, and so there was a difference in what the response times were measuring. Additionally, the lack of a distinct 'image-formation' stage may have influenced the 'quality' of the mental image that was formed in particular conditions.

Experiment 5b therefore aimed to explore the role of distinct 'image-forming' and 'decision-making' stages in the subsequent generation of a concurrent from a mental image. To this end, a modified version of a subset of the tasks used in Experiment 4 was developed. These tasks had the addition of a separate achromatic 'image formation' stage for the Object, Resolution and Transformation tasks. Both the Object and Resolution Tasks were modified because these were similar to the task used in Experiment 1, and it was of particular interest to see whether having an analogous trial procedure with the earlier study would result in the previously found pattern of results. The Transformation Task was also included as the mental rotation process was similar to the process used in Experiments 2 and 3. The Spatial and Visual Tasks were not included in order to reduce possible testing fatigue. Synaesthetes who had taken part in Experiment 4 were invited to take part in Experiment 5b. The predictions that were originally made for each synaesthete in Experiment 4 were also therefore made for the modified Object, Resolution, and Transformation Tasks.

6.7: Experiment 5b Method

Participants

The synaesthetes who initially completed the study in Experiment 4 were all invited to take part in the modified version in Experiment 5b. From the initial group of five, three were available: RW, DS and ZV (see Table 2.1 for participant details).

Materials and Procedure

Notwithstanding the addition of the ‘image formation stage’ to all trials, the same materials and procedure were used in the current study as were used in Experiment 4. Participants had written instructions, and first completed the Familiarisation Task, before moving on to the main trials tasks, in the order of the modified Object Task, the modified Resolution Task and the modified Transformation Task.

Modifications to the tasks: There was an ‘image formation stage’ at the start of every trial in the main tasks (See Figure 6.1 and 6.2). This consisted of an empty circle being shown on a white computer screen at the same time as the auditory prompt informed the participant which grapheme to visualise. At this time participants were asked to form a mental image of the indicated grapheme within the circle, so that it was as similar as possible to the examples shown in the earlier Familiarisation Task. They were told that they could take as long as they needed to do this, and once they had made it as clear and vivid as possible to press the space bar (see Appendix E). This was then followed immediately by the 'decision-making stage', in which the circle was divided into three equal sections, one of which was highlighted with a thick line and another with a dashed line. Participants were required to make the same decision for each task as made in the tasks in Experiment 4. It was in the 'decision-making' stage that the background colour was manipulated.

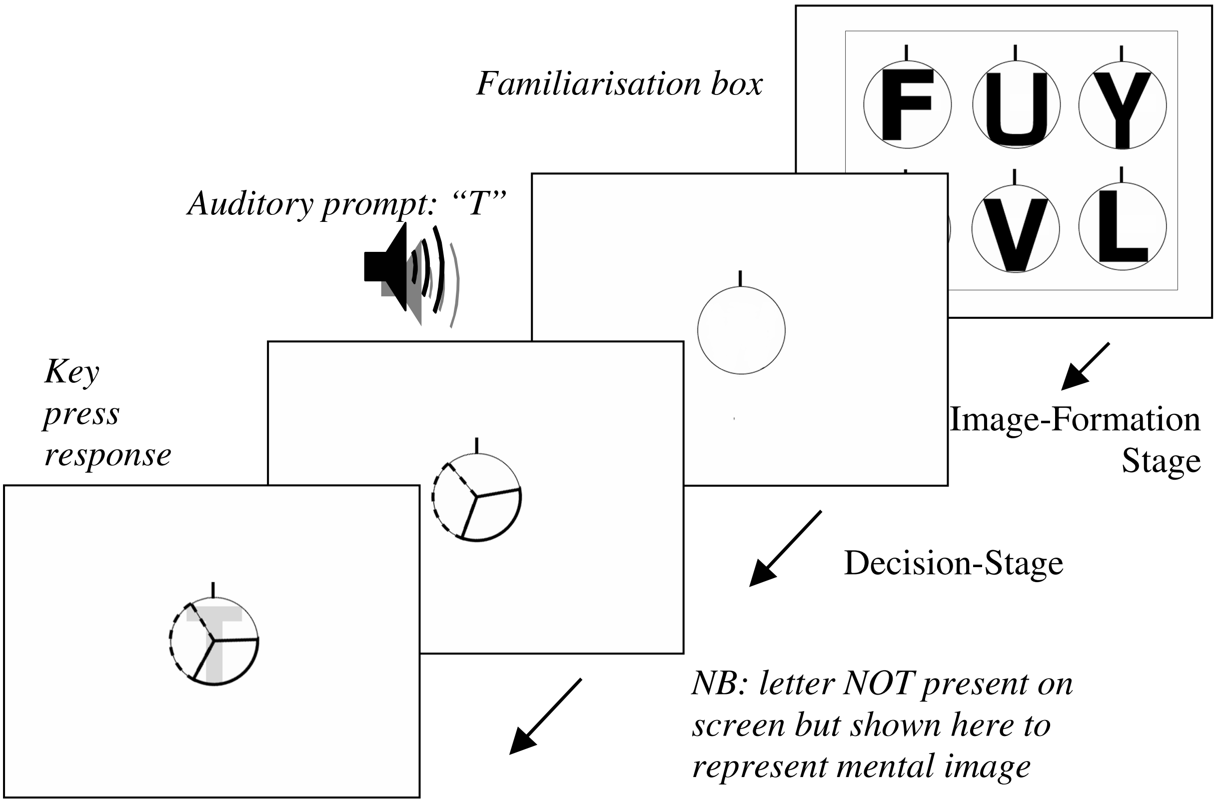


Fig 6.1: Modified trial procedure for Object and Resolution Task in Experiment 5b

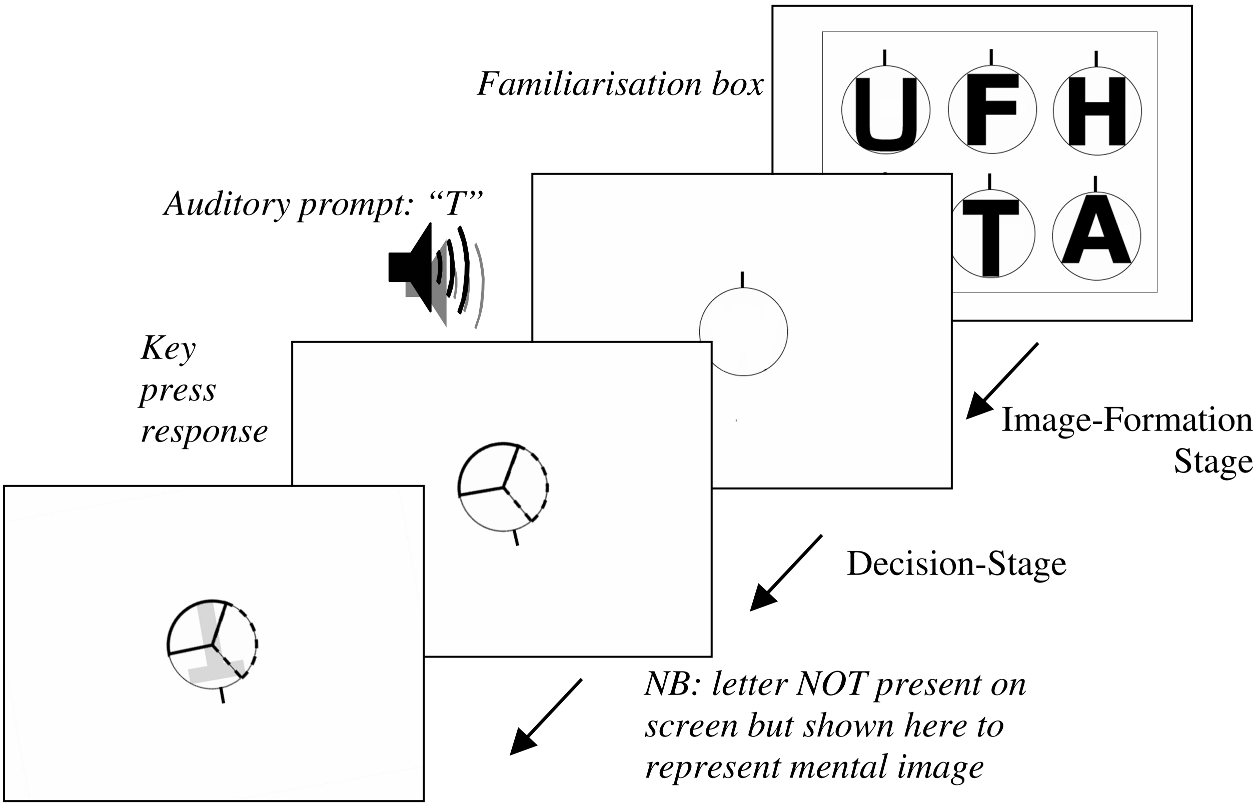


Fig 6.2: Modified trial procedure for Transformation Task in Experiment 5b

6.8: Experiment 5b Results

Like before, for all tasks the mean RT for each condition was calculated using trials answered correctly and trials that were treated as outliers (using stem and leaf procedures from SPSS package 10.1) were removed independently for all conditions. This procedure resulted in the removal of 1%, 3% and 4% of trials for all three tasks for ZV, RW and DS respectively.

Object Task:

Response time analysis: Table 6.7a shows the Object Task mean RTs for individual synaesthetes across the three colour conditions, and their associated

CEs. It can be seen that the direction of the colour effect was the same across the synaesthetes, with the slowest RT in the congruent condition. For DS, the assumption of homogeneity of variance was found to be violated (F(3, 76) = 3.94, p = .01) and therefore the Brown-Forsyth F ratio is reported, and an effect of colour that approached significance was found (F(3, 65) = 2.12, p = .1, η^2 = .08). Due to the relatively large difference between the congruent and opponent conditions further analysis was conducted to directly compare the two means, which found the opponent condition to be significantly faster than the congruent condition, with a large effect size (t(37) =2.52, p = .018, *d* = 0.85). A significant effect of colour was not found for ZV (F(3, 70) = 1.18, p = .32, η^2 = .05) or for RW (F(3, 77) = 0.56, p = .64, η^2 = .02).

Table 6.7a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the modified Object Task in Experiment 5b

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
RW	2042 (542)	1980 (810)	2008 (560)	1817 (512)	62	34
DS	3604 (2045)	3074 (1591)	2320 (989)	3371 (1960)	530	1284
ZV	2347 (713)	2049 (777)	2249 (632)	1982 (546)	298	98

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed slightly across the colour conditions for the synaesthetes (see Table 6.7b). Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all ps > .1) indicating a general absence of speed-accuracy trade-offs.

Table 6.7b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and ‘no colour’) in the modified Object Task in Experiment 5b

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
RW	11	3	4	3	1
DS	12	3	3	4	2
ZV	20	5	6	4	5

Resolution Task

Response time analysis: Table 6.8a shows the Resolution Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can be seen that the direction of the colour effect differed between synaesthetes. For RW, the assumption of homogeneity of variance was found to be violated (F(3, 65) = 5.98, p = .001) and therefore the Brown-Forsyth F ratio is reported, and an effect of colour approaching significance was found (F(3, 49) = 2.19, p = .1, η^2 = .09). Due to the relatively large difference between the incongruent and congruent conditions further analysis was conducted to directly compare the RTs for these conditions, which showed that the incongruent condition was significantly faster than the congruent condition (t(32) = 2.1, p = .049, *d* = 0.72). A significant effect of colour was not found for DS (F(3, 69) = 0.66, p = .58, η^2 = .03) or for ZV (F(3, 81) = 0.65, p = 58, η^2 = .02).

Table 6.8a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the modified Resolution Task in Experiment 5b

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
RW	1720 (532)	1427 (283)	1810 (660)	1524 (369)	293	-90
DS	1970 (973)	2059 (898)	2409 (1393)	2015 (851)	-89	-439
ZV	2630 (704)	2328 (860)	2481 (1024)	2331 (711)	302	149

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed slightly across the colour conditions for the synaesthetes (see Table 6.8b). Additionally, there were no significant correlations between ERs and RTs for any of the synaesthetes (all ps > .05) indicating a general absence of speed-accuracy trade-offs

Table 6.8b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the modified Resolution Task in Experiment 5b

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
RW	24	5	7	7	5
DS	19	4	5	6	4
ZV	10	1	3	3	3

Transformation Task

Response time analysis: Table 6.9a shows the Transformation Task mean RTs for individual synaesthetes across the three colour conditions, and their associated CEs. It can be seen that for all three synaesthetes the direction of the colour effect was the same, with the incongruent trials being faster than the congruent. One-way ANOVAs did not find a significant effect of colour for RW (F(3, 61) = 1.01, p = .39, η^2 = .05), for DS (F(3, 68) = 0.84, p = .48, η^2 = .04), or for ZV (F(3, 66) = 1.43, p = .24, η^2 = .06). For ZV comparing the congruent to the incongruent found that the difference approached significance with a large effect size (t(34) = 1.77, p = .09, *d* = 0.6).

Table 6.9a: Mean response times (RTs) and Congruency Effects (with standard deviations in parentheses) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the modified Transformation Task in Experiment 5b

	Colour condition				**Congruency Effect**	
Synaesthete	**Congruent**	**Incongruent**	**Opponent**	**No Colour**	**CE-S**	**CE-O**
RW	2575 (449)	2524 (1070)	2328 (685)	2761 (702)	51	247
DS	3270 (1548)	2721 (1278)	3138 (1826)	2594 (1107)	549	132
ZV	3192 (908)	2679 (816)	2869 (809)	2753 (652)	513	323

Error rate analysis: Comparing ERs shows that the number of errors each synaesthete made differed slightly across the colour conditions for the synaesthetes (see Table 6.9b). Additionally, there were no significant correlations between ERs and RTs for RW and DS (all ps > .1) indicating a general absence of speed-accuracy trade-offs for these synaesthetes. For ZV there was a significant correlation between ER and RT (r = .97, p = .026), indicating that as ZV made more errors in the Transformation Task she had a faster response time, suggesting a possible speed-accuracy trade-off.

Table 6.9b: Error rates (ERs) for synaesthetes as a function of colour condition (congruent, incongruent, opponent and 'no colour') in the modified Transformation Task in Experiment 5b

		Colour condition			
Synaesthete	**Overall**	**Congruent**	**Incongruent**	**Opponent**	**No Colour**
RW	29	8	8	7	6
DS	22	5	7	4	6
ZV	25	5	7	6	7

6.9: Experiment 5b Discussion

In Experiment 5b modified versions of the Object, Resolution and Transformation Tasks from Experiment 4 were used to explore the effect of separating the 'image-formation' and 'decision-making' stages on the possible subsequent generation of a concurrent. This was to explore the idea that the unexpected results for some synaesthetes with these tasks in Experiment 4 could be due to the stage in each trial that the colour manipulation was introduced. Three synaesthetes who had completed the earlier tasks completed modified versions of the Object, Resolution and Transformation tasks. The only modification was that each trial had a distinct 'image-forming' stage, in which there was no colour manipulation, which was followed by the 'decision-making' stage which involved colour manipulation. It was therefore predicted that the resulting colour effects for the modified Object and Resolution Tasks would be more similar to those found with the imagery task in Experiment 1. The findings of Experiment 5b however were again mixed, and the prediction was supported by only one of the three synaesthetes, showing the importance of individual differences in the way background colour can affect performance on imagery tasks.

Support for the idea that the unexpected results in Experiment 4 were due to the differences in trial sequence can be seen with ZV's results. A reliable colour effect had not been found with ZV in Experiment 1, but surprisingly she had shown a significant colour effect in the Object Task in Experiment 4. As expected, with the current study, when there was a distinct 'image-forming' and a distinct 'decision-making' stage, as was used in Experiment 1, she again did not show a significant effect of colour. In fact, although the difference was not significant, she was again found to be slower in the congruent condition than the incongruent, as she had been with Experiment 1, whereas in Experiment 4's Object Task she was faster in the congruent condition. Therefore, when ZV was able to form the image of the grapheme whilst looking at an achromatic background (in Experiment 1 and the current study, Experiment 5b), the introduction of colour in the decision-making stage did not reliably affect her performance. In contrast when colour was present from the start of the trial there was a significant colour effect with the Object Task in Experiment 4, and ZV had been slower in the incongruent condition (and specifically when the colour belonged to another grapheme, and not when it was the opponent colour). It could therefore be argued that when initially forming a mental image of a grapheme, the visual presentation of a colour belonging to a different grapheme inhibited her ability to form that image. This implies a bi-directionality in her synaesthesia, as has been shown with other synaesthetes when presented with coloured lines and shapes (Cohen Kadosh, Cohen Kadosh, & Henik, 2007; Cohen Kadosh & Henik, 2006). It could therefore be speculated that in order for the colour manipulation paradigm to show the conflict between the concurrent from a mental image and the ‘real’ colour that was visually presented, for ZV the colour needed to be presented in the ‘image-forming’ stage of the procedure.

In contrast to ZV, RW’s performance on Experiment 5b did not appear to be affected by the separation of the ‘image-formation’ and ‘decision-making’ stages. In Experiment 1 and Experiment 4’s Visual Task RW had been significantly slower in the incongruent condition, but surprisingly in Experiment 4’s Resolution Task she had been significantly faster in the incongruent condition. It was suggested that this difference in the direction of the effect could be due to the different stage that colour was introduced to the trials, as the tasks were very similar on all other aspects. However, in the current modified Resolution Task she was again found to be significantly faster in the incongruent condition, suggesting that the difference in direction of effect was unlikely to be due to the stage that the colour was introduced to the trials. In the Resolution Task, both when colour was present from the start of the trials (Experiment 4), and when it was only present in the second ‘decision-making’ stage of the trials (Experiment 5b), RW was faster when the background colour matched her synaesthetic colour for a different grapheme to the one she was visualising. The other main difference between the tasks was that she had a much higher error rate on both versions of the Resolution Task than she had in Experiment 1, suggesting that these tasks were more difficult. Consequently, it could be hypothesised that when RW found the task less demanding the incongruent condition was more of a distraction, potentially because she did not have to focus so much on grapheme form, and so was able to think of the grapheme usually associated with that colour. This suggests that depending on the amount of attention the imagery task required RW to focus on the grapheme form, the congruent colour can be either a help or a hindrance to task performance.

For DS the results from Experiment 5b suggest that separating the 'image-forming' and 'decision-making' stages did affect the subsequent colour effect, but produced a different pattern of results to that found previously. In Experiment 1 and Experiment 4's Resolution Task he had been slower in the incongruent condition. However, when the 'image-forming' and 'decision-making' stages were separated in the current study the colour effect in the modified Resolution Task was not significant, but surprisingly the congruent condition was found to be significantly slower in the modified Object Task. Moreover, the colour effect for the modified Transformation Task in Experiment 5b was not found to be significant, although the congruent condition was again slower than the incongruent. It would seem that a very different pattern of results was found for DS in the modified tasks in Experiment 5b, and at present there is no clear post hoc explanation for this, other than the idea that synaesthesia is not a unitary function; it would appear that due to the nature of the tasks being used, the synaesthetic concurrent can have varying effects on task performance, even within the same synaesthete.

In summary, the findings from Experiment 5b again highlight the importance of individual differences, as for each synaesthete the separation of the 'image-forming' and 'decision-making' stages had a different impact on the subsequent colour effect. While it appears that the separation of the stages had little effect on RW's performance on the Object, Resolution and Transformation Tasks, for both ZV and DS it did alter the effect of background colour on task performance. For RW it can be speculated that the difficulty level could be an important determinant in the direction of the colour effect, rather than the stage that colour was introduced to the trials. In contrast, ZV's performance on the modified Object and Resolution Tasks was more like her performance in Experiment 1, and it was possible to speculate that for ZV, for the background colour to interact with the concurrent, colour needs to be present in the 'image-forming' stage. DS's performance on the tasks in Experiment 5b was different again to his performance on all of the earlier tasks, highlighting how on a task such as the ones used in the current experiments, colour can affect performance in different ways within the same individual.

6.10: Experiment 5a and 5b General Discussion

Experiment 5a and 5b have further explored the role that purportedly different imagery processes play in the generation of a synaesthetic concurrent from an internally generated inducer. Experiment 5a replicated the tasks in Experiment

4 with a group of synaesthetes naïve to the testing methods. Experiment 5b used the same synaesthetes as Experiment 4, but with a modified set of tasks which had separate image-formation and decision-making stages with colour manipulation only occurring in the latter stage. Overall, the results from Experiment 5a can be used to suggest that the lack of support for some of the hypotheses of Experiment 4 was unlikely to be due to practice effects. As the heterogeneity of the synaesthete population has been shown many times, these results could simply reflect the differences between individual synaesthetes, and so the impact of practice effects can not be ruled out conclusively. However, it can be argued that the results of Experiment 5a provide less support for the role of practice effects, and so importantly, other explanations for the lack of colour effect for VE in Experiment 4's tasks need to be considered. Furthermore, the results from Experiment 5b highlighted the different ways colour can affect task performance on an imagery task, even for the same individual. Whilst the results from Experiment 5b showed that ZV's unexpected colour effect in Experiment 4 may have been due to the colour being present in the initial 'image forming' stage, the idea that this could also explain RW's unexpected direction of effect was not supported. Additionally, the variability of colour effects within the same individual was shown with DS, as he showed a pattern of results in Experiment 5b that was very different to all of the early imagery tasks.

Overall therefore, these experiments highlight not only the importance of individual differences again within the synaesthete population, but importantly the possible role of the individual's approach to the task. For some synaesthetes a consistent effect was not found across similar tasks, and so one potential explanation could be that the colour effect is dependent upon the strategy used by the individual synaesthete. Kosslyn (1994) suggested that with an individual imagery task there are many possible ways to approach it, and the tasks in the Visual Cognition Battery had been carefully designed so that each had a different imagery process that would be beneficial to task completion. Importantly, there were some consistencies with some synaesthetes' colour effects. However, the inconsistencies suggest that the way a synaesthete approaches the colour aspect of the task does not have to remain constant. As mentioned in the Discussion of Experiment 1, the impact that a synaesthete's approach to the colour aspect of a task has been highlighted before, in Yaro and Ward's (2007) study of synaesthetes' memories for congruently and incongruently coloured digit matrices. They noted that the synaesthetes reported different subjective experiences of the colour manipulation paradigm; some synaesthetes found the congruent condition beneficial to the memory task and others found it distracting. Consequently, these inconsistent findings across the imagery tasks, in addition to some apparently consistent ones, will have important implications for any conclusions to be made about cross-activation theory (Ramachandran & Hubbard, 2001a, 2001b) and the re-entrant feedback model of synaesthesia (Smilek & Dixon, 2002; Smilek, Dixon, Cudahy, & Merikle, 2001) in relation to eliciting a concurrent from an internally generated mental image of an inducer. This will be discussed further in Chapter 7.

Chapter 7 - Synaesthesia and mental imagery: a discussion

This final chapter provides a discussion of the thesis as a whole. The first section consists of a discussion of the research questions that have been addressed within the thesis, considering how the studies attempted to answer them, and the main inferences that can be drawn from the findings. Following on from this, the second section reflects on what the thesis, as a whole, can be seen to contribute to the field. Finally, the last section comprises a discussion of how the findings from the current thesis can be used to suggest future research directions within the dynamic synaesthesia research field.

7.1 - Overview of the research questions and how these have been answered

This thesis has addressed two main research questions:

1) Can an internally generated mental image of an inducer be shown to elicit a concurrent in grapheme-colour synaesthesia?
2) Is the type of imagery process that is used a determining factor in the generation of the concurrent?

Question 1: Can an internally generated mental image of an inducer be shown to elicit a concurrent?

This question was considered important as although previous studies have suggested that the external presentation of an inducer is not a necessary requirement for the generation of a concurrent (e.g. Smilek, Dixon, Cudahy, &

Merikle, 2002a), to date there had not been a systematic exploration of the possibility of generating a concurrent from a mental image of an inducer. Consequently, this was an aspect of synaesthesia that needed to be explored in order to further our understanding of synaesthesia, and to provide objective support for synaesthetes' reports that this was indeed the case. It was also an essential starting point, before other synaesthesia and mental imagery related questions, which have been raised in the literature, could be explored.

The method chosen to initially explore this question in Experiment 1 involved the novel combination of an experimental paradigm from the mental imagery literature with one used within the synaesthesia literature; synaesthetes generated mental images of graphemes and made a size-based decision about each image, whilst looking at background colours that were congruent or incongruent with the concurrent associated with the visualised grapheme. This method was deemed an appropriate way to be confident that the participants were forming mental images of the graphemes. Furthermore, by comparing the individual's response times across the different colour conditions it was possible to assess the impact of this colour manipulation on task performance. This colour-manipulation paradigm has been frequently used within the synaesthesia literature, with any reported difference in task performance between colour conditions being attributed to an interaction between the 'real' colour and the internally generated colour of the synaesthetic concurrent. It was predicted that if a concurrent was elicited from an internally generated mental image of a grapheme, such a colour effect would be found.

The results showed that, at the individual analysis level, there was a significant colour effect for four of the six synaesthetes tested in Experiment 1. To add support to the claim that the colour effect was due to the interaction with the synaesthetic concurrent, non-synaesthete matched controls did not show such a colour effect. Experiment 1 therefore provided the first empirical support for the subjective reports that an internally generated mental image of a grapheme can elicit a concurrent for some synaesthetes. It also suggested the possibility that the experimental paradigm created for the study could be a sound method for further exploring the determinants of the generation of a concurrent from a mental image of an inducer. It is important to note, however, that the colour effect for the synaesthetes was found at the individual rather than group-level of analysis, as the direction of the colour effect differed between synaesthetes. The prediction that performance would be faster in the incongruent condition, based on the findings of Smilek et al (2001), was only supported in the case of two of the four synaesthetes showing a significant effect of colour. Many studies of grapheme-colour synaesthesia have conducted their statistical analysis at the individual-level, as the magnitude of colour effects has been found to differ between individuals. This can be seen with studies using visually presented stimuli (Hubbard, Arman, Ramachandran, & Boynton, 2005) and also with studies using internally generated stimuli (Jansari, Spiller, & Redfern, 2006). However, few studies have reported a difference in the direction of the effect between synaesthetes, who have been tested with the same paradigm. Interestingly, this variation in direction of colour effect found with Experiment 1, mirrors that found with individual case-studies exploring the effect of background colour manipulation on performance on visual search paradigms; while the synaesthete reported by Smilek et al (2001) was shown to be slower at target detection in their congruent condition, Sagiv et al (2006) reported their synaesthete to be faster in the congruent condition, and Blake et al (2005) found no effect of background colour. Seemingly, therefore, as found with visually presented stimuli, the background colour manipulation paradigm does not have a consistent effect across synaesthetes on performance on a mental imagery task. For four of the six synaesthetes tested, comparison of task performance across the colour conditions suggested that mental images of graphemes can elicit concurrents for some synaesthetes, but the actual effect of this concurrent on performance can differ between individuals (the implications of this difference are discussed more in Section 7.2).

Question 2: Is the type of imagery process used a determining factor in the generation of the concurrent?

It has been widely suggested within the mental imagery literature (e.g. Mellet, Petit, Mazoyer, Denis, & Tzourio, 1998) that there are two broad categories of imagery process; object imagery processes (utilising the ventral visual pathway) and spatial imagery processes (utilising the dorsal visual pathway). Consequently, the second question was deemed to be a necessary continuation of the first question, as in order to fully understand the possible generation of a concurrent from a mental image of a grapheme, it was important to consider the type of imagery process being used. While Experiment 1 suggested that it was possible to generate a concurrent from a mental image of a grapheme ostensibly requiring the use of object imagery processes, from this study alone it was not clear whether this would be the case for an image using spatial imagery processes. Furthermore, due to the extant literature concerning the neural processes thought to be involved with these purportedly distinct imagery processes, this question was potentially important for further elucidating the cognitive processes underlying the generation of the concurrent. The observed colour effect found with Experiment 1 could be used to suggest that a concurrent was elicited but the actual level of grapheme representation at which the concurrent was elicited from was not clear. The use of object imagery processes that required the inspection of a high-resolution image meant that it was possible to be confident that the task involved the generation of depictive representation of the graphemes (see Section 2.1). The concurrent may therefore have arisen from the processing of the grapheme-form, as suggested to be a necessity by the cross-activation theory of synaesthesia (Ramachandran & Hubbard, 2001a). However, it may also have arisen from the concept of the grapheme that would also be generated by the task, and it is at this conceptual level of representation that the re-entrant feedback model predicts the concurrent to arise (Smilek, Dixon, Cudahy, & Merikle, 2001). Importantly, unlike object imagery processes, spatial imagery processes are thought to involve spatial representations but not depictive ones (Borst & Kosslyn, 2008). Therefore, the generation of a concurrent from spatial imagery processes would suggest that processing of the actual grapheme-form is not a necessity for the generation of a concurrent.

This idea was initially tested in Experiments 2 and 3 with the classic mirror-image discrimination paradigm, in which participants mentally rotated visually presented graphemes to decide whether the grapheme format was ‘normal’ or ‘backwards’ (Cooper & Shepard, 1973). This paradigm was chosen as it has been well documented to utilise spatial imagery processes (for example, Harris & Miniussi, 2003). The visual colour of the grapheme in Experiment 2, followed by the colour of the background in Experiment 3, was manipulated to be congruent or incongruent with each grapheme's concurrent. Interestingly, colour effects were found for two of the four synaesthetes tested when the colour of the stimuli was manipulated, but they did not show an effect of colour when the background colour was manipulated. In contrast, the two synaesthetes showing an effect of colour when the background colour was manipulated did not show an effect of colour when the grapheme colour was manipulated. Not only does this further illustrate the heterogeneity of the synaesthete population, these results suggest that either the spatial location (colour of grapheme or background) or amount of visually displayed colour could be an important determinant for measuring the effect of a synaesthetic concurrent. In relation to the question concerning the role of spatial imagery processes, these results provide support for the idea that a concurrent can be elicited for some synaesthetes from a mental image task based on spatial imagery processes. Importantly however, not all of the synaesthetes tested showed an effect of colour with both types of imagery process. Furthermore, for those that did show a colour effect with both types of imagery process, the way the concurrents interacted with the visually displayed colour seemingly varied between the tasks, suggesting a possible difference between a concurrent elicited from an object imagery process, and one elicited from a spatial imagery process. However, key differences between the imagery paradigms used meant that this was still open to speculation.

Consequently, to address this issue, the adapted Visual Cognition Battery (Kosslyn, Shephard, Burrage, & Thompson, 2006) was used in Experiments 4 and 5a and 5b to more systematically explore the role of different imagery processes. The Visual Cognition Battery comprised a set of comparable imagery tasks; two of which had rate-limiting object imagery processes, and two had rate-limiting spatial imagery processes. This had the benefit of providing the potential opportunity to replicate the findings from the earlier experiments (as one of the tasks in the battery had image resolution as its rate limiting process and another had image transformation or rotation). Furthermore, it provided the opportunity to expand the findings, with additional types of object and spatial imagery processes (of the remaining tasks, one had image complexity as its rate-limiting object imagery process, and the other had image scanning as its rate-limiting spatial imagery process). As before, the colour manipulation paradigm was incorporated into the design of the tasks, in order to assess the impact of colour on task performance. Due to the well documented range of individual differences in both imagery abilities and synaesthesia, synaesthetes who had taken part in the previous studies were again recruited for Experiment 4, allowing the direct comparison of performance across studies. It also permitted hypotheses to be formed for individual synaesthetes, based on their preceding task performances. For the synaesthetes who had previously shown a colour effect in Experiments 1 to 3, it was predicted that they would show the same colour effect on both tasks in the Visual Cognition Battery that used object imagery processes and / or both tasks using spatial imagery processes. The direction of the colour effect was also predicted using their previous performance.

Using the tasks from the Visual Cognition Battery to systematically explore whether the type of imagery process was a determinant of the generation of a concurrent also allowed the assessment of the reliability and validity of the earlier results. The results provided further support for the idea that a concurrent can be elicited from both spatial and object imagery processes for some synaesthetes. For example, the performance of DS on the object imagery and spatial imagery tasks in Experiment 4 reflected his performance on the object imagery task in Experiment 1 and his performance on the spatial imagery task in Experiment 2: with the object imagery processes he was slower in the incongruent condition suggesting a bi-directionality in his synaesthesia, and with the spatial imagery processes he was slower in the congruent condition suggesting the creation of a ‘camouflage effect’. This therefore provided further support for the idea that there is an important difference between the processes involved with these imagery processes, and how they interact with the processes involved in generating the synaesthetic concurrent.

The results from the tasks in Experiment 4 did not support all of the individual synaesthete predictions however. For example for some synaesthetes, the colour effects found with the initial task using object imagery processes in Experiment 1 were not found to be replicated in Experiment 4. As the task demands of Experiment 1 were very similar to those in the Object and Resolution Tasks in Experiment 4, it was predicted that individual synaesthetes would show a similar colour effect on these tasks as they also used object imagery processes. However, it was found that neither RW or VE showed the expected colour effect on these tasks, either in terms of the direction of the effect (for RW with the Resolution Task) or the reliability of the effect (for VE on both the Object and Resolution Tasks). The fact that the earlier findings were not replicated has important implications for any inferences made about the role of different imagery processes in the generation of a concurrent. It suggests that the actual imagery process used may not be a strong determinant of the concurrent generation, and that other factors may have played a more important role in either the actual concurrent generation in some cases, or the direction of the effect that this concurrent has on task performance in others. One possible reason for the lack of support was a possible over-familiarisation with the colour manipulation paradigm. However, this was not supported by a follow-up study in Experiment 5a with naïve synaesthetes, which further illustrated the heterogeneity of the synaesthete population.

Another possibility was that the expected colour effects in Experiment 4 were not found due to a difference in task procedure. In Experiment 1 there was a colour-free image forming stage, prior to the decision-making stage with colour manipulation, whereas the tasks from the Visual Cognition Battery combined the image-formation and decision-making stages, so that images were both formed and inspected against coloured backgrounds. To explore the effect of this difference in task procedure, modified versions of these tasks were conducted with some of the original synaesthetes in Experiment 5b. However, the results were again mixed. For one synaesthete the inclusion of a distinct colour-free image forming stage was seemingly important, as when the stages had been combined in Experiment 4 she showed a significant effect of colour, but when they were distinct, in Experiments 1 and 5b, she did not. In contrast, the inclusion of a distinct colour-free image forming stage was not found to be important for another synaesthete, as again she did not show the significant effect of colour that she had in Experiment 1. In addition, the third synaesthete to complete the modified imagery tasks showed another pattern of results that was different to both of his previous performances. The finding that the change in colour effects was unlikely to be due to the difference in task procedure suggests that other factors may be important determinants of the generation of a concurrent from a mental image, as discussed in Sections 7.2 and 7.3.

Overall therefore, in answer to the research questions posed by this thesis, the results collected with the chosen experimental methods showed that for some synaesthetes background colour did affect performance on a task requiring the generation and inspection of mental images of graphemes. Arguably, this provides initial empirical support for the idea that an internally generated mental image of a grapheme can elicit a concurrent for some synaesthetes. However, there was no clear answer to the question regarding the role of different imagery processes that could be generalised across even the small group of synaesthetes tested with the current studies. It would appear that for some synaesthetes the type of imagery process potentially was a determining factor, as for example KD only showed colour effects with the tasks based on spatial imagery processes. Overall however, the studies have shown that the role of different imagery processes is not clear cut. By testing a group of synaesthetes on a collection of tasks it has been possible to show that not only were there differences between individual synaesthetes, but also that there was variation within the same individual. These differences at the individual level were found with tasks that were thought to use distinct imagery processes, but interestingly also with tasks that were purportedly based on the same type of imagery process. Although there was no clear answer to the question of the role of various imagery processes, the systematic exploration of this question has highlighted some important aspects for synaesthesia research; and this leads the current chapter from a discussion of the individual research questions, to one concerning the contributions that the thesis can be seen to have made to the advancement of the field.

7.2 – How has the research advanced the field?

One of the main achievements of the work presented here has been the provision of empirical support for synaesthetes' subjective reports of a concurrent from an internally generated mental image. There have been documented anecdotal examples of these reports within the synaesthesia literature (Ramachandran & Hubbard, 2001a, 2003a), but to date there has not been any objective evidence to support these claims. Therefore the findings presented in this thesis make an important contribution to the synaesthesia literature. Whereas previous studies have documented the generation of a concurrent from externally presented inducers, the current studies provide some initial evidence of the generation of a concurrent from internally generated inducers. Like the mathematical Stroop paradigm studies (Dixon, Smilek, Cudahy, & Merikle, 2000; Jansari, Spiller, & Redfern, 2006; Smilek, Dixon, Cudahy, & Merikle, 2002a) the studies presented here have shown that the external presentation of an inducer is not a requirement for the generation of a concurrent. However, unlike those studies, the current studies specifically required the generation of mental images of inducers for successful task completion. Due to the requirements of the various tasks it is possible to be confident that such images were formed. The findings from the current studies are therefore important as they indicate that there is some potential support for one of the alternative explanations put forward to explain the generation of the concurrent without the apparent visual processing of the grapheme-form in the mathematical Stroop studies; that the synaesthetes may have spontaneously generated a mental image of the inducer, resulting in a pseudo-visual form (Hubbard, Manohar, & Ramachandran, 2006). Furthermore, the studies demonstrate how a paradigm from the mental imagery field can be combined with one from the synaesthesia field, to further our understanding of the synaesthetic experience.

The second way this research has advanced the field is through its systematic exploration of the generation of a concurrent from both object and spatial imagery processes. By using the findings of the more established body of research from the mental imagery field that suggest these processes make use of the ventral and dorsal pathway, it was possible to explore the level of inducer representation from which the concurrent is elicited. The debate within the synaesthesia literature concerning the necessity of the visual processing of the grapheme form, for the generation of the concurrent, has previously been explored by showing the effect of context on the concurrent generation (Dixon, Smilek, Duffy, Zanna, & Merikle, 2006), or by showing how concurrent generation is dependant on processes early in the visual processing stream (Hubbard, Manohar, & Ramachandran, 2006). The current research therefore represents a new approach to this issue, by focusing on the extent to which the top-down processes used to form the grapheme image would be expected to propagate back through the visual processing stream. As outlined in the earlier chapters, according to the cross-activation theory, the visual processing of the grapheme-form is the important determinant of the generation of a concurrent, and so this theory could be used to predict that a concurrent would be more likely to be elicited from an imagery task based on object-imagery processes than spatial imagery processes. This is because, according to this theory, the concurrent is generated through direct cross-activation between the adjacent grapheme processing and colour processing neuronal areas, early in the visual processing stream (Ramachandran & Hubbard, 2001b). Consequently, for a concurrent to be generated from a mental image the top-down processes would need to propagate back to the early visual areas. In contrast, from the perspective of the re-entrant feedback model, it could be predicted that the generation of a concurrent from a mental image would not be affected by the type of imagery process used. This is because this model suggests that the concurrent is elicited higher in the processing stream, when the concept of the grapheme feeds back to the earlier colour processing regions (Smilek & Dixon, 2002). Therefore, according to this theory, as long as the task evoked the concept of the grapheme the concurrent should be elicited (as found with the mathematical Stroop paradigm studies). With the experimental paradigms used in the current research it seems that for some synaesthetes it is possible to see the effect of the concurrent on performance on imagery tasks using both object and spatial processes (for example DS's performance in Experiment 4). This suggests that the processing of the visual form of the grapheme is not a requirement for the generation of a concurrent for these particular synaesthetes. Consequently, this does not provide support for the hypothesis based on the cross-activation theory. Importantly, for other synaesthetes colour effect was only found with tasks using spatial imagery processes (for example KD in Experiment 2 and ES in Experiment 5a), which again does not provide support for the cross-activation theory (assuming the spatial tasks did not involve processing of the grapheme-form). Therefore for some, the type of imagery process could potentially play a determining role in the generation of a concurrent. If future studies provide further support for this, then models of synaesthesia would need to account for these possible differences between synaesthetes.

Consequently, by systematically exploring the role of object and spatial imagery processes in the generation of the concurrent from a mental image of a grapheme, it has been possible to show how distinct imagery processes can lead to different effects for some synaesthetes. Therefore the third contribution of the studies presented in this thesis is the further illustration of the heterogeneity within the synaesthete population. As mentioned in Chapter 1, this is an issue of growing importance within the synaesthesia literature (Dixon & Smilek, 2005; Hubbard, Arman, Ramachandran, & Boynton, 2005; Ward, Li, Salih, & Sagiv, 2006). The current findings have shown that it is not possible to use the existing models of grapheme-colour synaesthesia to predict whether a concurrent will be elicited from different imagery processes for all synaesthetes. Furthermore, when a concurrent was found to be generated the effect this had on task performance also differed within individual synaesthetes. Some researchers have commented that the problem of conflicting findings across research groups may be due to differences in the synaesthetic experiences of individuals tested (Carriere, Eaton, Reynolds, Dixon, & Smilek, 2009; Dixon & Smilek, 2005), for example with regards to the subjective experience of the 'location' of the concurrent. However, with the data available about the synaesthetes tested it is not possible to explain the differences found with the current studies with regards to the often used 'associator' / 'projector' distinction. Another possible explanation could be the individual synaesthete's imagery ability, as individual differences are well documented with the mental imagery literature as well. This has been found with differences in the amount of activation of early visual areas in mental imagery tasks (Kosslyn, Thompson, Kim, Rauch, & Alpert, 1996; Slotnick, Thompson, & Kosslyn, 2005), and also in a recent study in which individuals with higher self-ratings of image vividness were more affected by background-colour congruency in a colour-word identification task (Cui, Jeter, Yang, Montague, & Eagleman, 2007). To address this possibility the VVIQ was used as a subjective measure of imagery ability with the current studies, and although this has its limitations (as discussed in Chapter 2) it was also not found to offer an explanation for the differences found. The reasons for these differences between synaesthetes could be an area for future research (as outlined in Section 7.3). However, by exploring the role of different imagery processes, the potential instability of the direction of these colour effects has been serendipitously illustrated, as this difference in colour effects can also be seen within the same individual. Therefore, it may be more important to understand why the direction of effect can differ within the same individual in tasks that purportedly use the same imagery process, before exploring the differences between individuals. It is also important to keep in mind the results of Experiments 2 and 3 which suggest that, for some synaesthetes, the effect of colour on task performance can be further compounded by both the attentional demands of the task, and the spatial location or amount of visually presented colour.

This potential instability of the direction of the colour effect links to the fourth contribution that the current research has made to the field; raising awareness of the need for future research to explore the possible role that an individual's approach to a task could have on the subsequent generation of a concurrent. This is also a possible explanatory factor for the individual differences found in these studies. The possible effect of an individual's approach to a task has been mentioned before in the synaesthesia literature; in Yaro and Ward's (2007) study of synaesthesia and memory, some synaesthetes subjectively reported that they found the visually presented congruent or incongruent stimuli distracting, some found it helpful, and some reported no noticeable effect. Potentially therefore, this could also have been the case with the synaesthetes in the current studies. As mentioned earlier, previous research has shown that presenting synaesthetes with incongruently coloured inducers results in the activation of cognitive control mechanisms (Weiss, Zilles, & Fink, 2005), and physiological signs of increased attentional load (Paulsen & Laeng, 2006), suggesting that the incongruent colour condition would be more distracting than the congruent condition. However, this does not mean that the same kind of response would result from the background colour manipulation paradigm, and the results of the current study clearly illustrate the variety of effects different background colours can have. This idea could be explored with a simple study assessing pupil dilation or other signs of increased arousal such as galvanic skin response, whilst synaesthetes complete an imagery task when looking at congruently and incongruently coloured backgrounds. It would be interesting to see whether physiological signs of arousal were associated with the condition that the synaesthete appeared to be more distracted by, with the behavioural measure. The idea that some synaesthetes find congruent background colour distracting and others find it helpful could also explain the conflicting findings with the visual search paradigms (Sagiv, Heer, & Robertson, 2006; Smilek, Dixon, Cudahy, & Merikle, 2001), and again is a possible explanation for the individual differences found within the synaesthete population. However, studies would also need to address *why* a congruent or incongruent background would be perceived as either helpful or distracting. A potential factor related to this could be differences in individuals' phenomenological experience of the concurrent.

Further support for the idea that a synaesthete's approach to the task could affect their performance, can be found within the mental imagery field, where this issue of 'approach to task' has been systematically explored to see the possible effect on the neural correlates of mental rotation. For example, Kosslyn et al (2001) asked participants to imagine an object being moved manually or independently. They found differing patterns of activation in the motor areas between the two conditions and suggested that this showed how task instructions can affect the activation of neural mechanisms involved in mental rotation. Further studies have documented how task instructions or pre-task activities can modulate the neuronal activation in spatial imagery processes (Wraga, Shephard, Church, Inati, & Kosslyn, 2005; Wraga, Thompson, Alpert, & Kosslyn, 2003). Consequently, with regards to the effect of the concurrent on mental imagery task performance, the individual's approach to the mental imagery task and/or the simultaneous presentation of different background colours could modulate the neural processes generating both the mental image of the grapheme and the synaesthetic concurrent. Furthermore, a study has suggested that the activation in the early visual areas during a mental imagery task could be related to how inherently interesting the object within the image is (Mazard, Laou, Joliot, & Mellet, 2005). Therefore, if a synaesthete finds visualising a grapheme against either a congruent or incongruent background more or less interesting, this could have an impact at a neuronal level, and may in turn have an effect on the depictive qualities of the actual image. Consequently, this is an issue that needs to be carefully addressed with both a behavioural and brain imaging approach in order to more fully explore possible explanatory factors for the individual differences.

The fifth contribution that this thesis can be seen to offer is in relation to the proposed models of grapheme colour synaesthesia. Although the findings do not provide direct support for either the cross-activation theory or the re-entrant feedback model, the findings can be used in the development of these models. The finding that for some synaesthetes the type of imagery process did appear to be a determinant of the concurrent generation, whereas for others it was not, needs to be explained by these models. In their original forms, neither model could explain these apparent individual differences. Following from this, the current results also show the importance of re-testing the same individuals on different occasions with the same task to establish test-retest reliability, as well as with different tasks that are thought to utilise the same process. Some of the individual's colour effects found in Experiment 1 were not replicated with tasks that were thought to use the same imagery process in Experiments 4 and 5, and in other cases the direction of the colour effect was found to differ. This has very important implications for the inferences that can be drawn from the current research, and highlights the importance of testing larger samples of synaesthetes at an individual-analysis level in order to get a more representative model of the underlying processes. The original models were based on studies that often used one or two synaesthetes. By testing a slightly larger sample of synaesthetes, and attempting to replicate the effects found, the current studies show the possible limitations of this approach. However, it is important to keep in mind that the field of synaesthesia research is dynamic, and a lot of the research currently available had been published since the start of this thesis. Furthermore, more recent accounts of the grapheme-colour synaesthesia models have stressed the role of both activation between V4 and VWFA and activation in the parietal areas (Carriere, Eaton, Reynolds, Dixon, & Smilek, 2009; Hubbard, 2007; Rouw & Scholte, 2007). Seemingly therefore, the role that both object and spatial processes play in the generation of the concurrent is increasingly being acknowledged.

The sixth contribution that the current studies can be seen to make to the field of synaesthesia, is the support for research concerning issues of bi-directionality in synaesthesia. A growing number of studies have documented the possible bi-directionality of grapheme-colour synaesthesia, so that not only does the inducer elicit the concurrent, but additionally it has been suggested that the concurrent can also be shown to elicit the concept of the inducer (Cohen Kadosh, Cohen Kadosh, & Henik, 2007; Cohen Kadosh et al., 2005; Johnson, Jepma, & de Jong, 2007). Importantly, the inclusion of the opponent colour condition in Experiments 4 and 5 illustrated how, for many synaesthetes, it was the condition in which the background colour was incongruent and importantly belonged to a different grapheme for that synaesthete, that colour was shown to most affect task performance. Therefore it was not simply a matter of having the ‘wrong’ colour that affected task performance, but a colour that was usually associated with a different grapheme. It can be speculated that for these synaesthetes the colour elicited a representation of a different grapheme, and so potentially made it more difficult to form an image of the prompted grapheme. It is not clear from the current results whether this was a conceptual representation or a depictive one, but the results can be used to imply that their synaesthesia is bi-directional to some extent. This is important, as again it illustrates how exploring synaesthesia and mental imagery can be used to approach other issues within the synaesthesia field by a different means. Furthermore, the question of bi-directionality could be used as a means to explore the individual differences found with the current imagery tasks. If an individual does have bi-directional synaesthesia, this might explain why the incongruently coloured background was a hindrance rather than the anticipated congruent background; one would expect that when the background colour belonged to another grapheme, which in turn elicited either the concept or even an image of that grapheme, this could be more distracting to task performance than any camouflage effect experienced with the congruent background.

7.3 –Future Directions

At this stage it is important to consider future directions for the growing field of synaesthesia research. One of the main issues arising from the discussion of how this thesis has advanced the field (see Section 7.2) is in relation to potential explanations for the individual differences found across these experiments. Therefore an essential future direction is to explore possible reasons for these observed differences between synaesthetes, both in terms of their performance on the current imagery tasks and also with paradigms used by other research groups. One such factor concerns phenomenological differences in synaesthetes' experiences of the concurrent. Although the current data suggests that the differences observed were unlikely to be due to the associator / projector distinction (Dixon, Smilek, & Merikle, 2004) it should be acknowledged that the method used for identifying the current synaesthetes as either associators or projectors was limited in its scope. Other issues that need to be considered by future studies include aspects such as the subjective location of the concurrent, and whether the concurrent is described as overlapping the grapheme or separate from the grapheme. These distinctions could be used to explain the differences found in the current experiments. For example, if colour was described as overlaying the grapheme then one could anticipate a congruent camouflage effect. This was found to be the case by Smilek et al (2001) with C's performance on a visual search task, who subjectively reports the concurrent overlaying the grapheme. This prediction could be tested in future studies with imagery tasks and also with a visual search paradigm, to see if synaesthetes' subjective description of their experience of the concurrent can be used to predict the effect of colour on task performance.

Another possible explanatory factor future studies need to further explore is the issue of bi-directionality (as described in Section 7.2). In order to see whether this can be used to explain the individual differences observed, the paradigms used by Cohen Kadosh and colleagues to measure bi-directionality (Cohen Kadosh, Cohen Kadosh, & Henik, 2007; Cohen Kadosh et al., 2005) could be used to see if synaesthetes' performances on these can successfully predict either a subsequent camouflage effect (i.e. expecting synaesthetes to be slower on the imagery task in the congruent condition if not showing evidence of bi-directionality) or a slower performance in the incongruent condition (if bi-directional). Furthermore, to explain apparent differences within the same individual but on different tasks, future studies need to look at issues such as the speed of image formation, and see how this links with the temporal sequence of the concurrent being elicited from the inducer. For example, if on a particular imagery task an individual is very slow at image formation, the colour may be expected to have more impact. The potential impact of the temporal sequence of events has been illustrated with ZV's performance in Experiments 4 and 5b, which clearly illustrated the effect of including or not including a distinct colour-free image formation stage. Of course future studies would also need to consider the idea that factors such as the phenomenological differences in the colour experience, the extent to which an individual shows bi-directionality, and the speed of image formation will also interact with each other. Consequently, differences between individuals are further complicated and this illustrates why a relatively simple distinction such as the associator/projector one may not be enough to fully capture the heterogeneity within the synaesthete population.

In relation to the research questions addressed in the current thesis, it will also be important for future studies to consider other experimental paradigms to the one used already to explore the generation of a concurrent from a mental image of a grapheme. This is especially so considering that all of the synaesthetes tested in Experiments 1 to 4 subjectively report that visualising a grapheme results in a synaesthetic concurrent, but not all showed significant colour effects with the paradigm used. This could suggest that the paradigm was not sensitive enough for all synaesthetes. The apparent instability of the colour effects, and potential effect of an individual's approach to the task, also suggest that other paradigms need to be explored. Using an experimental paradigm that requires a less complex task procedure may help to alleviate these limitations, especially in relation to differences in task approach. One such approach would be a combination of a signal detection paradigm, with a mental image inspection paradigm. Participants could be given two simultaneous tasks to do; the first would involve a forced-choice response to a series of questions about graphemes. The questions would require the generation of a mental image of the grapheme for the correct response. At the same time, participants would complete a signal detection task, and indicate when a target signal was visually detected on a computer screen. These targets would be coloured to be congruent or incongruent with the individual synaesthete's concurrents. If a concurrent is elicited during the mental imagery task the synaesthetes could be expected to be faster to detect the signal when it is congruently coloured with the grapheme being visualised, due to the priming caused by the imagery task. For non-synaesthetes, no such colour effect would be expected. This paradigm could also be used to assess the role of different imagery processes as the questions about the grapheme image could relate to the grapheme's object and spatial properties. Furthermore, it could be used to assess the role of attention in the generation of a concurrent from a mental image, by requiring the inspection of implicit and explicit properties of the grapheme image (see Thompson, Kosslyn, Hoffman, & van der Kooli, 2008).

Future research exploring mental imagery and synaesthesia would also benefit from the use of neuroimaging techniques, in addition to this behavioural approach. In Experiments 1 to 5, the generation of a concurrent has been measured by comparing an individual's different response times across the various colour conditions, which is an established behavioural method, frequently used within the synaesthesia literature. Furthermore, presumption of the generation of a mental image, and the use of different mental imagery processes, has been based on the use of tasks designed according to the findings of numerous behavioural and neuroimaging studies within the mental imagery field, that have generated our knowledge of these purportedly distinct imagery processes. The use of neuroimaging techniques would be able to add to these findings, by helping to clarify possible reasons for the individual differences documented in the current thesis. For example, methods such as EEG could be used to see the temporal sequence of processes, from the generation of the mental image to the concurrent, in an attempt to unpick the perceptual / conceptual issues. Additionally, methods such as fMRI could be used to explore the individual differences in patterns of brain activation. These differences have been well documented in relation to primary visual cortex activation during mental imagery tasks (Slotnick, Thompson, & Kosslyn, 2005), and also within the few studies of synaesthesia with the generation of a concurrent from visually presented stimuli (Hubbard, Arman, Ramachandran, & Boynton, 2005; Sperling, Prvulovic, Linden, Singer, & Stirn, 2006). Interestingly, a recent study using diffusion tensor imaging (DTI) has indicated possible differences in structural connectivity between synaesthetes (Rouw & Scholte, 2007), and it would be interesting to explore differences in the generation of a concurrent from a mental image in relation to possible structural differences.

Finally, an essential future direction for research concerning mental imagery and synaesthesia is to explore synaesthesia and mental imagery within different sensory modalities. The studies presented in the current thesis have focused on one type of synaesthesia and mental imagery within one sensory modality, which was an important initial step to allow a systematic exploration. As the majority of the research in the imagery field has focused on visual mental imagery, and grapheme-colour is the most studied form of synaesthesia, it made sense from both a practical and theoretical point of view to start with these, as we have the most knowledge about them. However, an important next step would be to expand on this, as mental imagery is not limited to the visual domain, and there are many other forms of synaesthesia. For example, there is a growing body of research concerning auditory imagery, and this could be used to explore sound-colour synaesthesia or word-taste synaesthesia, in relation to concurrents elicited from internally generated spoken words or internally generated music. As with the current research, the important thing would be to design a task that would measure both the auditory image and the potential concurrent. As grapheme-colour synaesthesia is unusual, in that it occurs within the same modality, while most forms of synaesthesia are inter-modal, these types of cross-sensory synaesthesia would be especially interesting to explore, to see if the underlying processes would elicit a concurrent from an inducer that was internally generated from within a different sensory modality. Overall therefore, although it was important to focus on one form of synaesthesia for the current thesis, future research needs to ensure that the focus is not limited to this, in order to further our understanding of these atypical sensory experiences.

7.4 - Summary

To summarise, the work presented in the thesis has explored the question of whether a synaesthetic concurrent could be shown to be elicited from an internally generated mental image of an inducer. As there are thought to be different types of imagery process, the research has also addressed the issue of whether these processes would themselves be a determinant in the concurrent generation. By doing this it was also possible to assess the two main models of grapheme-colour synaesthesia, and their different positions concerning the level of grapheme representation that the concurrent is thought to arise from. This is because while object imagery processes can be shown to generate depictive representations, spatial imagery processes are not thought to involve these earlier visual processes. Importantly, colour effects were found for some synaesthetes, which supports the idea that a concurrent can be elicited by a mental image for some synaesthetes (all synaesthetes, except one, showed a significant colour effect in at least one of the tasks). Interestingly, the direction of colour effect was found to differ between synaesthetes, and also within the same synaesthete on tasks that purportedly used same imagery process. However, consistent patterns were found for some synaesthetes, showing that for some individuals object imagery processes or spatial imagery processes may be important determining factors. It is possible to use ideas from the synaesthesia literature to explain some of the directions of effect. For example, it appears that the visual colour being part of individual synaesthete's own colour alphabet can be important, suggesting bi-directionality within their synaesthesia. The impact of cognitive control mechanisms on their task performance has also been considered. In relation to the issue of whether the concurrent is elicited from a conceptual or perceptual representation of the inducer, the results as a whole cannot definitively support either view. Furthermore, the lack of a consistent pattern, even within the same individual, suggests that not only are individual differences important, but also that the individual's actual approach to the task may be important. Based on these findings a number of important suggestions have been made, with regards to how they can be used to advance the field of synaesthesia research in addition to future research directions. Overall, by systematically exploring a previously unexplored aspect of synaesthesia, with a novel combination of experimental paradigms from the two different fields of research, it has been possible to further our understanding of synaesthesia and to highlight important considerations for future research.

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APPENDIX A: Experiment 1 Participant Instructions

Your task in this study will be to create a visual mental image of the letter indicated (from the audio cue) within a circle on the computer screen. When you have made your image as clear and vivid as you can (after pressing the space bar) the circle will be divided into 3 equal sections. One of the sections will have a thick line around it and one will have a dashed line around it. The whole circle will also have either a coloured background or no colour background.

You need to decide whether the section of the circle with the thick line or dashed line would contain the majority of the letter. You also need to say what colour the background is. The trident will disappear as soon as you name the colour so make sure you make your decision about "dashed" or "thick" before naming the colour

You need to speak into the microphone and say 2 things:
1 - the name of the colour (eg 'red') or 'no colour'
2 - 'dashed' or 'thick'

Press the spacebar when you are ready to begin the practice trials

APPENDIX B: Experiment 2 Task 1 Participant Instructions

In this study each stimulus will either be presented its 'normal' or 'backward' (i.e. mirror image) form.

You need to decide whether it is presented in its 'normal' or 'backwards' form.

Please say either 'backwards' or 'normal' into the microphone to give your decision.

Please decide as quickly as you can without sacrificing accuracy.

When you are ready to start the practice trials please press the spacebar.

Experiment 2 Task 2 Instructions

In this study each stimulus will be rotated at an angle, in either its 'normal' or 'backward' (i.e. mirror image) form.

You need to mentally rotate the stimulus to its upright position, and to decide whether it is presented in its 'normal' or 'backwards' form.

Please say "backwards' or 'normal' into the microphone to give your decision.

Please decide as quickly as you can without sacrificing accuracy.

When you are ready to start the practice trials please press the spacebar.

APPENDIX C: Experiment 3 Participant Instructions

Welcome to the study.

In this study you will see a series of letters and numbers presented one at a time in the centre of the screen.

Your task is to work out if the letter / number is "normal" or "backwards".

Each letter / number will either be upright or rotated away from the upright position.

When the letter/number is not upright you need to mentally rotate the stimulus to its upright position. You can then decide whether it is presented in its 'normal' or 'backwards' form.

For each answer please say either 'normal' or 'backwards' aloud into the microphone. Please decide as quickly as you can without sacrificing accuracy.

When you are ready to start the practice trials please press the spacebar.

APPENDIX D: Experiment 4 and 5a Participant Instructions

General Overview

Thank you for agreeing to take part in this study. The study is looking at visual mental imagery of letters and digits. Throughout the study you will need to form visual mental images, and by this I mean that you will need to “create an image in your mind’s eye”, or “visualise” certain objects. Some people find this an easy thing to do and can visualise quite detailed scenes in their mind’s eye, and other people find it more difficult and only get a vague feeling of an image. Please try to create as clear and detailed images as you can throughout this study, but do not worry if you find some tasks more difficult than others.

In this study there are a number of trial phases. For each phase you will be required to perform a different task involving mental images of letters and digits. You will receive detailed task instructions and practice trials at the start of each trial phase, and you will also have the chance to ask questions.

Before starting the trial phases you need to complete a familiarisation stage. In this stage you will see a series of letters and digits, presented one at a time, in a circle on the computer screen. You will have the chance to practise forming mental images of these letter/digits, which will be important for the trial phases of the study. For the success of this study it is vital that the mental images you use in the trial phases are the same as those you learn to form in the familiarisation stage.

If you have any questions at this point please feel free to ask.

When you are ready please ask the experimenter for the instructions for the familiarisation stage.

Instructions for Familiarisation Phase

The aim of the first phase of the study is to give you the chance to familiarise yourself with the stimuli you will need to form mental images of during the upcoming trial phases. For the success of this study it is essential that the images of the letters/digits you form in the trial phases are the same as the pictures of the letter/digits you will see in this familiarisation stage. Please pay close attention to the exact shape, size and location of each letter/digit within the circle it is presented in.

In this phase a letter or digit will appear within a circle for a fixed amount of time. Please study it carefully. When the letter/digit disappears, take as much time as you need to visualize the character within the circle. When you have made your image as clear and vivid as you can, press the space bar and the letter or digit will reappear. At this point, please carefully compare your visualized image to the actual character, and correct your mental image if necessary. Press the space bar again to move on to the next letter.

If you have any questions at this point please feel free to ask.

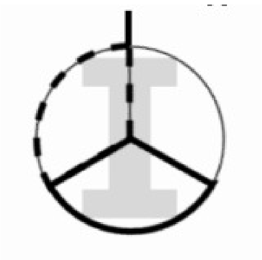
When you are ready to begin the familiarisation phase please tell the experimenter.

Instructions for Trial Phase 1 (O)

At the beginning of each set of 24 trials, you will see a familiarization box containing 6 of the circles and characters that you have seen, just to refresh you memory. Please take as much time as you need to study the letters and digits, as they will be used in the upcoming trials.

During these trials you will see a series of circles on the screen that have been divided into 3 equal sections. One section of each circle has a THICK line around it and another has a DASHED line around it.

You will hear a spoken prompt from the computer, to let you know which letter or digit to visualise. As carefully and precisely as you can please visualise this prompted letter or digit within the divided circle on the screen. Decide as quickly and accurately as possible which section of the circle, the THICK or DASHED section, would have more of its area covered by the visualised character. [Please be aware the actual characters will not appear during the actual trials]



In the above example the THICK section clearly has more of its area covered by the “I” so you would press the THICK button [the experimenter will show you which buttons to press for your choices].

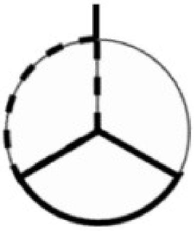
Before the trials begin, there will be an example and a set of five practice trials. If you have any questions at this point please feel free to ask.

When you are ready to begin the practice trials please tell the experimenter.

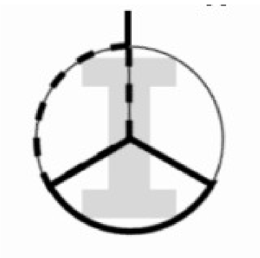
Instructions for Trial Phase 2 (R)

At the beginning of each set of 24 trials, you will see a familiarisation box containing 6 of the circles and characters that you have seen, just to refresh you memory. Please take as much time as you need to study the letters and digits, as they will be used in the upcoming trials.

During these trials you will see a series of circles on the screen that have been divided into 3 equal sections. One section of each circle has a THICK line around it and another has a DASHED line around it.



You will hear a spoken prompt from the computer, to let you know which letter or digit to visualise. As carefully and precisely as you can please visualise this prompted letter or digit within the divided circle on the screen. Decide as quickly and accurately as possible which section of the circle, the THICK or DASHED section, would have more of its area covered by the visualised character. [Please be aware the actual characters will not appear during the actual trials]



In the above example the THICK section clearly has more of its area covered by the “I” so you would press the THICK button [the experimenter will show you how to press the buttons].

Before the trials begin, there will be an example and a set of five practice trials. If you have any questions at this point please feel free to ask.

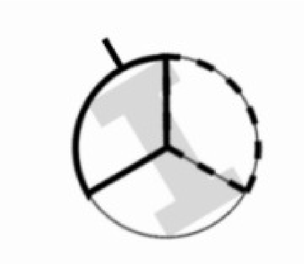
When you are ready to begin the practice trials please tell the experimenter.

Instructions for Trial Phase 3 (T)

At the beginning of each set of 24 trials, you will see a familiarisation box containing 6 of the circles and characters that you have seen, just to refresh you memory. Please take as much time as you need to study the letters and digits, as they will be used in the upcoming trial phase.

During the trials, you will see a series of circles divided into sections. One section of each circle will be outlined in a THICK line and another with a DASHED line. You will hear a spoken prompt from the computer, to let you know which letter or digit to visualise. There will also be a small tick mark somewhere on the circumference of the circle.

Please visualize the corresponding block character image and rotate it so that the top of the letter/digit is in line with the tick mark (see example below). When you have mentally rotated the letter or digit, please decide which section of the circle would have more of its area covered by the character, the THICK or the DASHED section, if the rotated character were actually present. Indicate your decision by pressing the appropriate labelled key. **Please do NOT turn your head when doing these trials**. Instead, just mentally rotate the characters in your mind's eye. [Please be aware the actual characters will not appear during the actual trials]



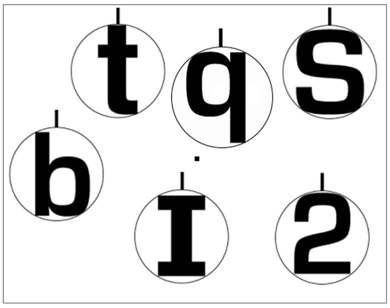
In the above example the THICK section clearly has more of its area covered by the “I” so you would press the THICK button [the experimenter will show you how to press the buttons].

Before the trials begin, there will be an example and a set of five practice trials. If you have any questions at this point please feel free to ask.

When you are ready to begin the practice trials please tell the experimenter.

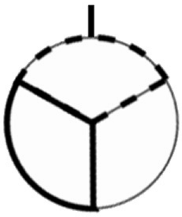
Instructions for Trial Phase 4 (S)

The next phase is very different from the other four. As before, at the beginning of each set of 24 trials, you will see a familiarisation box containing 6 circles marked with the block characters that you have seen. However, in this trial phase the circles are placed randomly within the box, as shown in the example below.

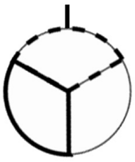


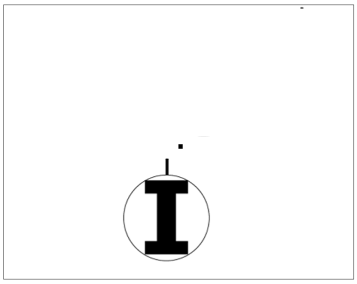
For each familiarisation box, please take as much time as you need to study the location of the circles within the box, as **you will need to remember their locations** during the trial session. Please pay attention to each character's location in the box in relation to dot in the centre of the box.

During the trials, you will see a series of circles divided into sections. One section of each circle will be outlined in a THICK line and another with a DASHED line. You will hear a spoken prompt from the computer, which corresponds to one of the block characters within the circles in the familiarization box.



For each trial, **visualize the circle's location** in the familiarization box where you saw it before, and, by pressing the appropriate labelled key, indicate which section of the circle would fall closest to the box's centre point. [Please be aware the actual characters will not appear during the actual trials]

Circle on the screen = 

Remember location of familiarisation box = 

In the above example the DASHED section clearly falls closer to the centre of the box so you would press the DASHED button [the experimenter will show you how to press the buttons].

Before the trials begin, there will be an example and a set of five practice trials. If you have any questions at this point please feel free to ask.

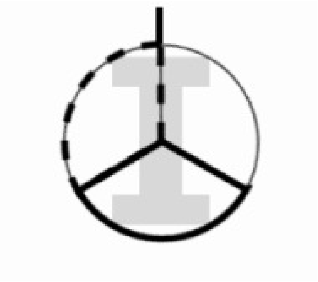
When you are ready to begin the practice trials please tell the experimenter.

Instructions for Trial Phase 5 (B)

At the beginning of each set of 24 trials, you will see a familiarisation box containing 6 of the circles and characters that you have seen, just to refresh you memory. Please take as much time as you need to study the letters and digits, as they will be used in the upcoming trial phase.

During the trials, you will see a series of circles divided into sections. One section of each circle will be outlined in a THICK line and another with a DASHED line. You will hear a spoken prompt from the computer, which corresponds to one of the block characters within the circles in the familiarization box.

Decide as quickly and accurately as possible which section of the circle, the THICK or DASHED section, would have more of its area covered by the grey block character.



In the above example the THICK section clearly has more of its area covered by the “I” so you would press the THICK button [the experimenter will show you how to press the buttons].

Before the trials begin, there will be an example and a set of five practice trials. If you have any questions at this point please feel free to ask.

When you are ready to begin the practice trials please tell the experimenter.

APPENDIX E – Experiment 5b Participant Instructions

General Overview

Thank you for agreeing to take part in this study. The study is looking at visual mental imagery of letters and digits. Throughout the study you will need to form visual mental images, and by this I mean that you will need to “create an image in your mind’s eye”, or “visualise” certain objects. Some people find this an easy thing to do and can visualise quite detailed scenes in their mind’s eye, and other people find it more difficult and only get a vague feeling of an image. Please try to create as clear and detailed images as you can throughout this study, but do not worry if you find some tasks more difficult than others.

In this study there are a number of trial phases. For each phase you will be required to perform a different task involving mental images of letters and digits. You will receive detailed task instructions and practice trials at the start of each trial phase, and you will also have the chance to ask questions.

Before starting the trial phases you need to complete a familiarisation stage. In this stage you will see a series of letters and digits, presented one at a time, in a circle on the computer screen. You will have the chance to practise forming mental images of these letter/digits, which will be important for the trial phases of the study. For the success of this study it is vital that the mental images you use in the trial phases are the same as those you learn to form in the familiarisation stage.

If you have any questions at this point please feel free to ask.

When you are ready please ask the experimenter for the instructions for the familiarisation stage.

Instructions for Familiarisation Phase

The aim of the first phase of the study is to give you the chance to familiarise yourself with the stimuli you will need to form mental images of during the upcoming trial phases. For the success of this study it is essential that the images of the letters/digits you form in the trial phases are the same as the pictures of the letter/digits you will see in this familiarisation stage. Please pay close attention to the exact shape, size and location of each letter/digit within the circle it is presented in.

In this phase a letter or digit will appear within a circle for a fixed amount of time. Please study it carefully. When the letter/digit disappears, take as much time as you need to visualize the character within the circle. When you have made your image as clear and vivid as you can, press the space bar and the letter or digit will reappear. At this point, please carefully compare your visualized image to the actual character, and correct your mental image if necessary. Press the space bar again to move on to the next letter.

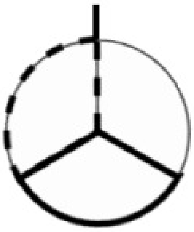
If you have any questions at this point please feel free to ask.

When you are ready to begin the familiarisation phase please tell the experimenter.

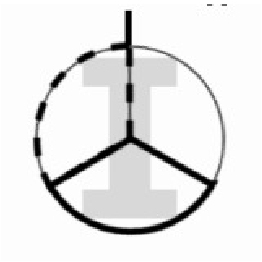
Instructions for Trial Phase 1 (O)

At the beginning of each set of 24 trials, you will see a familiarization box containing 6 of the circles and characters that you have seen, just to refresh you memory. Please take as much time as you need to study the letters and digits, as they will be used in the upcoming trials.

During these trials you will see an empty circle on the computer screen and hear a spoken prompt from the computer, to let you know which letter or digit to visualise. As carefully and precisely as you can please visualise this prompted letter or digit within the empty circle on the screen. Once your visual image is as clear and vivid as you can make it press the spacebar. The circle will then be divided into 3 equal sections. One section of each circle has a THICK line around it and another has a DASHED line around it.



Decide as **quickly** and **accurately** as possible which section of the circle, the THICK or DASHED section, would have more **of its area covered by the visualised character**. [Please be aware the actual characters will not appear during the actual trials]



In the above example the THICK section clearly has more of its area covered by the “I” so you would press the THICK button [the experimenter will show you which buttons to press for your choices].

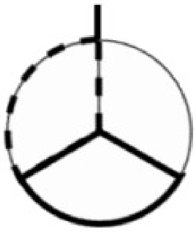
Before the trials begin, there will be an example and a set of five practice trials.

If you have any questions at this point please feel free to ask.

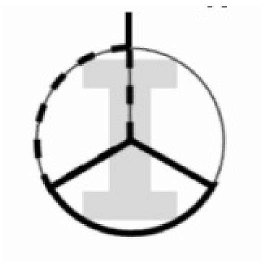
When you are ready to begin the practice trials please tell the experimenter.

Instructions for Trial Phase 2 (R)
At the beginning of each set of 24 trials, you will see a familiarisation box containing 6 of the circles and characters that you have seen, just to refresh you memory. Please take as much time as you need to study the letters and digits, as they will be used in the upcoming trials.

During these trials you will see an empty circle on the computer screen and hear a spoken prompt from the computer, to let you know which letter or digit to visualise. As carefully and precisely as you can please visualise this prompted letter or digit within the empty circle on the screen. Once your visual image is as clear and vivid as you can make it press the spacebar. The circle will then be divided into 3 equal sections. One section of each circle has a THICK line around it and another has a DASHED line around it.



Decide as **quickly** and **accurately** as possible which section of the circle, the THICK or DASHED section, would have **more of its area covered by the visualised character**. [Please be aware the actual characters will not appear during the actual trials]



In the above example the THICK section clearly has more of its area covered by the “I” so you would press the THICK button [the experimenter will show you how to press the buttons].
Before the trials begin, there will be an example and a set of five practice trials.
If you have any questions at this point please feel free to ask.
When you are ready to begin the practice trials please tell the experimenter.

Instructions for Trial Phase 3 (T)
At the beginning of each set of 24 trials, you will see a familiarisation box containing 6 of the circles and characters that you have seen, just to refresh you memory. Please take as much time as you need to study the letters and digits, as they will be used in the upcoming trial phase.

During these trials you will see an empty circle on the computer screen and hear a spoken prompt from the computer, to let you know which letter or digit to visualise. As carefully and precisely as you can please visualise this prompted letter or digit within the empty circle on the screen. Once your visual image is as clear and vivid as you can make it press the spacebar. The circle will then be divided into 3 equal sections. One section of the circle will have a THICK line around it and another a DASHED line around it. There will also be a small tick mark somewhere on the circumference of the circle.

Please rotate your image so that the top of the letter/digit is in line with the tick mark (see example below), and then decide as **quickly** and **accurately** as possible which section of the circle, the THICK or DASHED section, would have **more of its area covered by the visualised character,** when rotated. **Please do NOT turn your head when doing these trials**. Instead, just mentally rotate the characters in your mind's eye. [Please be aware the actual characters will not appear during the actual trials]

In the above example the THICK section clearly has more of its area covered by the “I” so you would press the THICK button [the experimenter will show you how to press the buttons].

Before the trials begin, there will be an example and a set of five practice trials. If you have any questions at this point please feel free to ask.

When you are ready to begin the practice trials please tell the experimenter.

APPENDIX F:

Copy of published material: Spiller, M.J. & Jansari, A.S. (2008) Mental imagery and synaesthesia: is synaesthesia from internally-generated stimuli possible? *Cognition*, 109, 143-151