The effects of stimulus competition and voluntary attention on colour-graphemic synaesthesia

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Colour-graphemic synaesthetes experience vivid colours when reading letters, digits and words. We examined the effect of stimulus competition and attention on these unusual colour experiences in 14 synaesthetes and 14 non-synaesthetic controls. Participants named the colour of hierarchical local–global stimuli in which letters at each level elicited synaesthetic colours that were congruent or incongruent with the display colour. Synaesthetes were significantly slower to name display colours when either level was incongruent than when both levels were congruent. This effect was significantly reduced when synaesthetes focused attention on one level while the congruency of letters at the ignored level was varied. These findings suggest that competition between multiple inducers and mechanisms of voluntary attention influence colour-graphemic synaesthesia.

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INTRODUCTION

For most individuals, stimulation of one sense yields a unique perceptual experience in that modality. For people with synaesthesia, however, stimulation of one sensory modality results in perceptual experiences in one or more other modalities [1]. For example, tasting a particular food may induce a distinct tactile sensation [2], or hearing a specific sound may result in a visual experience [3]. Synaesthesia is an intriguing phenomenon that provides a valuable opportunity to investigate the way in which the brain represents and binds sensory and conceptual properties of objects [1]. Recent neuroimaging studies have identified areas of brain activity associated with synaesthetic colours triggered by auditorily presented words, including a region of the fusiform gyrus thought to be involved in colour perception (V4) [4], and a posterior region of the inferior temporal cortex that has been implicated in the integration of colour and form [5].

The most common form of synaesthesia is that in which letters, numbers, or words induce vivid colour experiences, known as colour-graphemic synaesthesia [1]. The synaesthetic colour induced by a particular graphemic form is highly consistent over time [3]. This consistency provides the basis for objective measures of synaesthetic experiences. One widely used approach has been to measure the time taken for a synaesthete to name the display colour of a letter or digit, and to manipulate the relationship between the display colour and the synaesthetic colour elicited by the character. If synaesthetic colours arise automatically, then pitting them against display colours should result in interference. Several studies have shown that synaesthetes are slower to name display colours of characters when the synaesthetic colour they induce is different from the display colour (a synaesthetically incongruent display) compared with when the synaesthetic colour and display colour match (synaesthetically congruent displays) [6–9]. This synaesthetic congruency effect suggests that synaesthetic experiences are relatively automatic and involuntary.

In previous studies of the synaesthetic congruency effect, colour-inducing stimuli have been presented in isolation, so that a single synaesthetic colour was in competition with the display colour. Here, we used hierarchical stimuli in which a global letter was formed by multiple local letters. The aim was to investigate the effect on synaesthesia of having multiple inducing stimuli simultaneously present within a single display. A further aim was to investigate the effect of having participants direct their attention to either global or local letters within these hierarchical stimuli.

For conventional hierarchical displays, such as those introduced by Navon [10], small (local) letters or digits form a large (global) letter or digit of either the same identity (e.g. a large A composed of small As; consistent stimuli), or of a different identity (e.g. a large A composed of small Bs; inconsistent stimuli). Typically, participants in local–global tasks respond faster to targets that appear at global rather than local levels, and interference is greater from global than local distractors (the global precedence effect) [10,11]. When synaesthetes view inconsistent local–global stimuli, they...
report perceiving the colour of the character to which they are currently attending, rather than a blend of synaesthetic colours elicited by the two characters, or two distinct colours simultaneously [12,13]. As they switch their attention between local and global levels, they report that their synaesthetic colour changes accordingly [13]. These anecdotal observations suggest that when two inducing characters are presented simultaneously, the synaesthetic colours induced by the local and global forms compete for selection, in a manner that may be analogous with other kinds of perceptual rivalry [14]. It might be predicted, therefore, that a synaesthetic colour induced by the currently attended letter would compete more strongly with a display colour than a synaesthetic colour associated with the ignored letter.

In order to investigate this hypothesis, we presented colour-graphemic synaesthetes and non-synaesthetic controls with coloured local–global stimuli. Participants were required to name display colours in a speeded task to quantify the effect of competition between synaesthetic colours induced by local–global stimuli and display colours. For trials in which the local and global letters were consistent, the synaesthetic colour induced could be either congruent (Fig. 1a) or incongruent (Fig. 1b) with the display colour. For trials in which the local and global forms were inconsistent, the global letter could induce a synaesthetic colour that matched the target colour, so that only the local letters were incongruently coloured (Fig. 1c); or the local letters could induce a synaesthetic colour that matched the target display colour, so that only the global letter was incongruently coloured (Fig. 1d). Note that for these two types of stimulus, only one level (local or global) elicited a synaesthetic colour that did not match the display colour. Unlike paradigms that have used traditional Navon-type stimuli [10], letter identity was irrelevant to the participants’ task in the current experiments, which always involved identification of the colour of the stimulus display. The time taken to name the display colour provided a measure of the synaesthetic congruency effect.

MATERIALS AND METHODS

Experiment 1: If there is competition between the synaesthetic colour elicited by a letter and the display colour in which it appears, then synaesthetes should be slower to name display colours when a local or global letter elicits a synaesthetic colour different from the display colour, than when these colours are congruent. Moreover, the extent of any such competition should be greater when letters at both local and global levels induce incongruent synaesthetic colours, than when the letters at only one of the levels (local or global) induce an incongruent colour.

Participants: Fourteen colour-graphemic synaesthetes (12 female; 12 right-handed; mean age (± s.d.) 46 ± 13.1 years, range 20–62 years), and 14 age-, sex- and handedness-

![Fig. 1. Examples of the four stimulus types presented to one of the synaesthetes, E.S., for whom A elicits red and B elicits green. (a) Local and global letters consistent; the synaesthetic colour elicited by the letter is congruent with the display colour (both levels congruent condition). (b) Local and global letters consistent; the synaesthetic colour elicited by the letter is incongruent with the display colour (both levels incongruent condition). (c) Local and global letters inconsistent; the synaesthetic colour elicited by the global letter is congruent with the display colour, whereas the synaesthetic colour elicited by the local letters is incongruent with the display colour (local incongruent condition). (d) Local and global letters inconsistent; the synaesthetic colour elicited by the local letters is congruent with the display colour, whereas the synaesthetic colour elicited by the global letter is incongruent with the display colour (global incongruent condition).](image-url)
matched non-synaesthetic controls (mean age 47.1 ± 13.6 years; range 21–66 years) participated in the study. The mean ages of the two groups did not differ significantly (t(26) = −0.21, p > 0.05). All participants gave informed consent.

**Apparatus:** An IBM compatible Pentium III (128 MHz) computer was used for stimulus presentation and data recording. Stimuli were presented on a 17 inch Samsung SyncMaster 710(Ms) fast-decay monitor, with a vertical refresh rate of 75 Hz. A Labtec AM-22 microphone connected to the serial port of the computer was used to record vocal onset times. Errors were scored manually.

**Stimuli:** Each synaesthete selected display colours that best matched his/her synaesthetic colours for six letters using a standard computer-generated palette. These letters were used to construct a unique set of coloured local–global stimuli for each synaesthete. Non-synaesthetic participants viewed the identical stimuli to the synaesthete with whom they were matched, to control for any extraneous effects of particular letter–colour pairings. When the identity of the local and global letters was consistent (e.g., a global A made of local As), the synaesthetic colour this letter elicited could be either congruent or incongruent with the display colour (Fig. 1a: both levels congruent; Fig. 1b: both levels incongruent). When the identity of the local and global letters was inconsistent (e.g., a global B made of local As), the synaesthetic colour induced by the letter at each level could be either congruent or incongruent with the display colour. In the global incongruent condition, the synaesthetic colour induced by the local letters was congruent with the display colour, whereas the local letters were equally likely to induce a synaesthetic colour that was congruent or incongruent with the display colour (Fig. 1c). In the local incongruent condition, the synaesthetic colour induced by the global letter was congruent with the display colour, and the synaesthetic colour induced by the local letters was incongruent (Fig. 1d).

Global letters subtended 6.84° of visual angle vertically and ~4.35° horizontally. Local letters subtended 0.46° vertically and horizontally. All stimuli were presented individually on a uniform grey background.

**Procedure:** All four stimulus types (both levels congruent, both levels incongruent, global incongruent, local incongruent) were randomly intermingled, so that participants could not predict whether conflict between synaesthetic and display colours would arise at the local or global level. Participants responded by naming aloud the colour of each hierarchical stimulus as quickly as possible. No feedback was given regarding speed or accuracy. Participants completed four blocks of 96 trials, each block containing 24 trials for each of the four conditions. The order of blocks was counterbalanced across participants. Each block was preceded by eight practice trials. A chin rest was used to maintain viewing distance at 50 cm.

**Experiment 2:** We modified the colour-naming task from Experiment 1 so that within a block the letters at one level (local or global) always elicited a synaesthetic colour that was congruent with the display colour. Participants were instructed to attend to this level throughout the block. Letters at the ignored level elicited either congruent or incongruent synaesthetic colours with equal probability. Voluntary allocation of attention to one level should increase the competitive strength of letters at this level [15], and reduce the strength of letters at the ignored level. If attention modulates synaesthetic colour experiences, then the magnitude of the congruency effect should be reduced when conflict with the display colour arises at the ignored level of the stimulus.

Participants, apparatus and stimuli were identical to those of Experiment 1, except that trials in which both local and global letters induced incongruent synaesthetic colours (both levels incongruent) were excluded.

**Procedure:** In the attend global condition, two blocks of 96 trials were presented, each containing equal numbers of both levels congruent and local incongruent stimuli, randomly intermingled. Thus, the global letter always induced a synaesthetic colour that was congruent with the display colour, whereas the local letters were equally likely to induce a synaesthetic colour that was congruent or incongruent with the display colour. Participants were instructed to attend to the global letter and to ignore the local letters. In the attend local condition, a further two blocks of 96 trials were presented, each containing equal numbers of both levels congruent and global incongruent trials, randomly intermingled. In these blocks, local letters always induced a synaesthetic colour that was congruent with the display colour, whereas the global letter was equally likely to induce a synaesthetic colour that was congruent or incongruent with the display colour. Participants were directed to attend to the local letters and to ignore the global form. As in Experiment 1, the task in both the attend global and attend local conditions was to name the display colour as quickly as possible. All other aspects of the procedure were the same as in Experiment 1.

**Results**

**Experiment 1:** Outliers, defined as colour-naming times (NTs) 3 s.d. above or below an individual’s mean for each condition, were removed prior to statistical analysis. NTs less than 100 ms were regarded as anticipations and also removed. Using this procedure, 7% of trials were discarded. A further 12% of trials were excluded due to microphone errors (triggering by extraneous noise or failures to detect vocal onset times). Corrections were made where necessary for violations of sphericity, and post-hoc tests were Bonferroni corrected for multiple comparisons.

Figure 2 shows NTs for synaesthetes and controls for each congruency condition. A mixed ANOVA on mean correct NT with the factors of group (synaesthetes, controls) and congruency (both levels congruent, both levels incongruent, global incongruent, local incongruent) revealed a significant main effect of congruency (F(1.98, 51.41) = 16.61, p < 0.001), no significant main effect of group (F < 1), and a significant group × congruency interaction (F(1.98, 51.41) = 6.11, p < 0.005). Post-hoc pairwise comparisons were performed for each group. As evident in Fig. 2, synaesthetes were slower in the both levels incongruent, global incongruent and local incongruent conditions, than both levels congruent condition (p < 0.01). In addition, synaesthetes were significantly slower in the both levels incongruent...
condition than either the global incongruent or local incongruent conditions \((p < 0.05)\), which did not differ from each other \((p > 0.05)\). As expected, non-synaesthetic controls showed no significant differences between any of the congruency conditions \((p > 0.05)\). Error rates for each group were low \((< 3\%)\) and followed the pattern of NTs, with no evidence of a speed/accuracy trade-off.

**Experiment 2:** Approximately 3\% of trials were removed as outliers and a further 5.5\% of trials were lost due to microphone errors. Participant errors accounted for \(\sim 3\%\) of trials and followed the NT data.

Figure 3a shows NTs for synaesthetes and controls when they focused their attention on the global letter (attend global). A mixed ANOVA on mean correct NT with the factors of group (synaesthetes, controls) and congruency (both levels congruent, local incongruent) revealed a significant main effect of congruency \((F(1,26) = 8.107, p < 0.01)\), no significant main effect of group \((F(1,26) = 1.53, p > 0.05)\) and a significant group \(\times\) congruency interaction \((F(1,26) = 5.40, p < 0.05)\). Simple main effects by group showed that synaesthetes were slower on local incongruent than both levels congruent trials \((p < 0.01)\), whereas there was no such difference for controls \((p > 0.05)\).

Figure 3b shows NTs for synaesthetes and controls when they focused their attention on the local letters (attend local). A mixed ANOVA on mean correct NT with the factors of group (synaesthetes, controls) and congruency (both levels congruent, global incongruent) revealed a significant main effect of congruency \((F(1,26) = 29.37, p < 0.001)\), but no significant main effect of group \((F < 1)\), and no significant group \(\times\) congruency interaction \((F < 1)\). The absence of an interaction is due to the fact that non-synaesthetic controls also tended to be somewhat slower in the global incongruent condition relative to the both levels congruent condition. This suggests that the normal global precedence effect [11,16] may have countermanded participants’ attempts to attend to the local level only.

To determine whether focused attention reduced the magnitude of the interference caused by synaesthetic incongruency, synaesthetes’ performances were compared for the same display conditions across Experiments 1 and 2. Paired samples \(t\)-tests revealed that the congruency effect in the attend local condition of Experiment 2 was significantly smaller than the congruency effect for the identical displays in Experiment 1 \((p < 0.05)\). In contrast, the congruency effect in the attend global condition of Experiment 2 was not significantly different from that for identical displays in Experiment 1 \((p > 0.05)\).
DISCUSSION

In Experiment 1 we examined the effect of manipulating synaesthetic congruency on colour-naming times using local–global stimuli in which two synaesthetic inducers were present simultaneously. Synaesthetes were slower in the both levels incongruent condition, where both local and global forms induced a synaesthetic colour incongruent with the display colour, than in the both levels congruent condition, where the synaesthetic colour and the display colour matched. For stimuli in which the identity of local and global forms differed, there was no difference between global incongruent and local incongruent conditions. There were no differences in the colour-naming times of non-synaesthetic controls across the manipulations of congruency, as would be expected given the absence of synaesthetic colour experiences in this group.

The finding that synaesthetes’ colour-naming times were shorter in the global incongruent and local incongruent conditions than in the both levels incongruent condition suggests that synaesthetic colours may be determined in part by whether a participant is currently focusing attention on the congruent or incongruent level. Thus, in the both levels incongruent condition, conflict between synaesthetic and display colours would be expected to occur regardless of whether attention was focused on the local or global form. In contrast, in the global incongruent and local incongruent conditions, such conflict would arise at only one level, with the letter at the other level eliciting a congruent colour. If participants happened to be focusing on the congruent letter on a given trial, the competitive strength of the (ignored) incongruent letter would be reduced. In Experiment 1, however, we did not constrain the level at which participants attended. Therefore, in Experiment 2, we had participants focus their attention on just one level of the stimuli throughout a block of trials. Only letters that induced colours congruent with the display colour appeared at the attended level, whereas on 50% of trials, randomly intermingled with fully congruent stimuli, letters that induced incongruent colours appeared at the ignored level. If directing attention to one level of a hierarchical stimulus reduces the competitive strength of the synaesthetic colour from the ignored inducer, then the congruency effect should also be attenuated under these conditions.

In Experiment 2, we investigated whether focused attention can reduce the effect of an incongruent inducer on colour naming of hierarchical stimuli. Under conditions in which synaesthetes focused attention on letters that induced congruent synaesthetic colours, and ignored letters that elicited incongruent colours, a significant congruency effect remained. Thus, even an actively ignored letter can induce a synaesthetic colour that interferes with naming of a display colour. In the attend local condition, however, the magnitude of the congruency effect was significantly reduced relative to the non-focused attention conditions of Experiment 1. Thus, actively ignoring a letter can reduce its synaesthetic effect, consistent with anecdotal reports of synaesthetic individuals [12,13].

The modulation of the synaesthetic congruency effect by mechanisms of voluntary selective attention is similar to the influence of attention on the classic Stroop effect. In the standard Stroop task, participants are slower to name ink colours of incongruently coloured colour words (e.g. the word ‘red’ written in green) than congruent or colour-neutral words (e.g. the word ‘green’ or ‘chair’ written in green) [17,18]. It has been demonstrated, however, that the magnitude of the Stroop effect can be modulated by selective attention. For example, directing attention to a colour-neutral word presented simultaneously with an incongruent colour word reduces but does not eliminate interference from the incongruent colour word on colour-naming [19]. Other studies have shown that cueing a single letter in the word compared to cueing all the letters reduces the impact of incongruent colour–word stimuli [20]; and that colouring just a single letter in a colour word eliminates the Stroop effect [21]. The general explanation for such modulations of the Stroop effect is that diverting attention from the word reduces the efficiency of semantic access, and therefore reduces the conflict between the colour word and the ink colour to be named [22]. Similarly, our manipulations of attention may have reduced the efficiency with which the inducing letters were able to activate representations of synaesthetic colours, thus reducing the magnitude of the synaesthetic congruency effect.

Further research is necessary to determine whether attentive processing of an inducing letter or number is mandatory for synaesthetic colours to occur, or whether such colours can be elicited in the absence of attention. We have previously demonstrated, using a priming paradigm in which letters were masked from awareness, that the synaesthetic congruency effect does not occur when participants are unable to overtly identify inducing stimuli [6]. A prominent theory of attention proposes that in order for an object to be consciously recognised, attention is required to bind the attributes or features of the object together [23]. Thus, it is also possible that attention is necessary for binding of colour and form in synaesthesia [24].

In conclusion, we have demonstrated that when two inducing characters are presented simultaneously, the extent to which they lead to activation of synaesthetic colours is influenced by the focus of selective attention. Thus, although synaesthetic colours are elicited automatically, they are modulated by competition between multiple inducing stimuli and by mechanisms of voluntary attention.

REFERENCES

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