THE ROLE OF MEANING IN GRAPHEME-COLOUR SYNAESTHESIA

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Abstract

When the synaesthete, J, is shown black graphemes, in addition to perceiving the black digits or letters she also experiences highly specific colours that overlay the graphemes (e.g., 5 is pink, S is green). We used ambiguous graphemes in a Stroop-type task to show that the exact same forms (e.g., 5) can elicit different synaesthetic colours depending on whether they are interpreted as digits or letters. J was shown strings of black digits (e.g., 3 4 5 6 7) or words (e.g., M U S I C) for 1 sec. All but one of the graphemes then disappeared and the remaining grapheme changed to a colour that J had to name as quickly as possible. The key trials involved coloured graphemes that were ambiguous (e.g., the 5 in the strings above could be interpreted either as a digit or as a letter). On congruent trials, the colour of the ambiguous target grapheme was the same as J's photism for the digit or letter interpretations of the grapheme. On incongruent trials, the colours of the ambiguous target graphemes were different than the colours of J's photisms for the digit or letter interpretations of the graphemes. On digit-context incongruent trials, the ambiguous graphemes were presented in J's colour for the letter-interpretations of the graphemes, whereas on letter-context incongruent trials, the ambiguous graphemes were presented in J's colours for the digit-interpretations of the graphemes. Thus the same ambiguous grapheme (e.g., a pink 5) served as a congruent stimulus in one context and an incongruent stimulus in another context. J's response times showed that ambiguous graphemes elicited different photisms depending on whether they were interpreted as digits or letters. This finding suggests that it is not the form but the meaning of graphemes (whether they are interpreted as digits or letters) that determines the colours of synaesthetic photisms.

Key words: grapheme-colour, synaesthesia, digits, letters, meaning

Introduction

For people with grapheme-colour synaesthesia, viewing digits or reading text can be a colourful experience. When J is shown a string of black digits (e.g., 2, 3, 4, 5, 7) each grapheme consistently induces a conscious experience of a highly specific colour. For J, a 4 is a "semi-dark, sky blue" colour, and a 5 is "medium-dark pink". Letters too, induce highly specific colour experiences for this 22-year old female synaesthete. H is a "slightly dark, melon brown" colour, and S is "medium-dark green". The specific synaesthetic colour experience associated with each grapheme does not change over time (Baron-Cohen et al., 1993; Svartdal and Iversen, 1989), and numerous studies have found that when synaesthetes view graphemes, their photisms are elicited independent of their intentions, or in other words, "automatically" (Dixon et al., 2000, 2004a, 2004b; Mattingley et al., 2001; Mills et al., 1999; Odgaard et al., 1999; Wollen and Ruggiero, 1983). For some synaesthetes, whom we refer to as *associators*, the synaesthetic colour is experienced in their "mind's eye" and for other synaesthetes, whom we call *projectors*, the synaesthetic colour is experienced as a colour overlay that sits atop the visually presented grapheme (Dixon et al., 2004a, 2004b).

In the present experiment, we explored the nature of projected synaesthetic colours by evaluating whether such synaesthetic colour experiences depend primarily on the *meaning* of graphemes or whether they depend primarily on the *visual form* of the graphemes. On the one hand, certain lines of evidence suggest that projected synaesthetic colour experiences may depend primarily on the visual form of graphemes. For instance, projector synaesthetes can perceptually group stimuli together using photisms (Ramachandran and Hubbard, 2001a) and photisms can aid in the identification of graphemes when there is perceptual crowding (Ramachandran and Hubbard, 2001b). Also, projected photisms can improve the efficiency of visual search (Smilek et al., 2001, 2003; Palmeri et al., 2002). Such findings suggest that synaesthetic colours might arise relatively early in perception. Because the form of a grapheme is processed earlier in the perceptual system than is the meaning of a grapheme, one can argue, as did Ramachandran and Hubbard (2001b, 2003), that synaesthetic colours are determined primarily by the visual form of a grapheme and that the identity of a grapheme (i.e., the meaning) is not essential for activating its synaesthetic colour.

On the other hand, several aspects of the subjective reports of synaesthetes are consistent with the idea that the meaning of a grapheme plays a critical role in determining the colour of the synaesthetic experience. First, synaesthetes who we have interviewed typically report that for any given letter, their synaesthetic colours are unaffected by variations in either the size or the font of the graphemes. The fact that a myriad of graphemic forms can elicit identical colours is consistent with the idea that it is the identity or, in other words, the meaning of a grapheme that activates the colour, rather than the specific form of a grapheme. Second, synaesthetes report that ambiguous graphemes (e.g., a 5 that can be interpreted as either the digit 5 or the letter S) induce different synaesthetic colours depending on whether they are interpreted as digits or letters (Smilek et al., 2001). For example, we recently asked a mother to show her five-year old synaesthetic son two separate displays: a string of digits (e.g., 37564) and a string of letters (HPSOA). She asked him to name the colours that he experienced for the graphemes in each display. Even though the middle grapheme in each display was exactly the same, he reported experiencing different colours for this grapheme in the digit and letter context. Importantly, he did not report any oscillations between colours; rather he consistently reported one colour in the digit context and a different colour in the letter context. Likewise, when the synaesthete C (c.f., Dixon et al., 2000) was asked to describe her colours for ambiguous graphemes embedded in different contexts, she said "If I definitely know it's the number 5, then it's immediately green, and if I definitely know it's the letter S, then it's immediately fuchsia". Similar anecdotal reports of top-down colouring of ambiguous graphemes have also been reported by Ramachandran and Hubbard (2001b). Anecdotes such as these suggest that the meaning of the graphemes might play a primary role in determining the colours of photisms.

Whether synaesthetic colours are primarily determined by the form of a grapheme or by the meaning of a grapheme has important implications for the types of neural architectures that can be proposed to explain how synaesthetic colours arise in synaesthesia. If synaesthetic colours depend primarily on form, then it would be reasonable to surmise that synaesthetic colours result primarily from cross activation between the areas of the brain that process form and the areas of the brain that process colour, with minimal or no influence from areas of the brain that process the meaning. Such a cross-talk model has been proposed by Ramachandran and Hubbard (2001a, 2001b, 2003). In contrast, if synaesthetic colours depend primarily on the meaning of graphemes, then feedback from areas of the brain that process meaning to areas of the brain that process colour would be essential to any model of grapheme-colour synaesthesia. Such feedback or reentrant models have been proposed by Grossenbacher and Lovelace (2001), as well by our research group (Smilek et al., 2001; Smilek and Dixon, 2002; Dixon et al., 2004a, 2004b).

Even though a number of researchers have discussed the possible roles of form and meaning in the generation of synaesthetic colours (Ramachandran and Hubbard, 2001b; Smilek and Dixon, 2001), to date, there has been only one study in which this issue was investigated directly. Myles et al. (2003) used Stroop methods to test PD, a projector synaesthete, who experiences photisms for both digits and letters (for PD, a 2 is green and a Z is brown). PD was asked to name the colours of ambiguous graphemes (e.g., a green 2) embedded in lists of sequentially presented digits or letters. When the green 2 appeared within a list of digits, PD was faster to name its colour (green) than when the same stimulus appeared in a list of letters. Myles et al., attributed this Stroop-like interference to PD's photisms. When she was biased to interpret this stimulus as a digit, the green 2 induced a green photism that speeded colour naming, but when she interpreted it as a letter, the green 2 induced a brown photism that interfered with colour naming. It should be noted that only three ambiguous graphemes were tested, and only two of these graphemes elicited these context-dependent Stroop effects.

Although the study reported by Myles et al. (2003) constitutes a first step towards demonstrating that meaning plays a critical role in determining the colour of synaesthetic experiences, there are two limitations to the study that need to be addressed before strong conclusions are made. First, the study reported by Myles et al. (2003) involved only a single synaesthete and therefore, it remains unclear to what extent these findings generalize to other synaesthetes. Second, the study used only three ambiguous graphemes and failed to find evidence for conceptual influences for all of the graphemes that were used. That only two of the three graphemes showed the predicted context dependent Stroop effects indicates either that the conceptual influences were not particularly strong or that the manipulation of meaning by context used in this study was not maximally effective.

In the present experiment, we extended the findings reported by Myles et al. (2003) by addressing the limitations described above. First, to establish the generality of context-dependent Stroop effects, we replicated the findings with a different projector synaesthete. Second, to establish the robustness of the findings, we used a larger set of five ambiguous graphemes (see Table I). Third, to establish the reliability of these context-dependent Stroop effects we attempted to elicit these effects in two different conditions (one in which digit and letter context trials were presented in blocks and another in which they were intermixed). Finally, we used a more salient manipulation of context than used by Myles et al. (2003). Specifically, rather than using sequences of unambiguous digits or letters to bias interpretation of the ambiguous graphemes we increased the salience of the context by directly embedding the ambiguous graphemes either within strings of digits or within strings of letters forming words. J was shown strings of black digits (e.g., 3 4 5 6 7)

TABLE I

The grapheme-colour pairings experienced by J, along with the ambiguous graphemes used in Experiments 1 and 2

Digits	Synaesthetic colours	Letters	Synaesthetic colours	Ambiguous grapheme
2	Orange	Z	Reddish purple	2
3	Medium light green	B	Baby blue	3
4	Semi dark, sky blue	H	Slightly dark, brown melon	4
5	Medium dark pink	S	Medium dark green	5
7	Purple	T	Dark red	7

or 3, 4 or 5-letter words (e.g., MUSIC) for 1 sec. All but the ambiguous grapheme then disappeared and this grapheme changed to a colour that J had to name as quickly as possible.

Based on the findings reported by Myles et al. (2003), we expected that each ambiguous grapheme would trigger one colour in the digit context and a different colour in the letter/word context. If the same form was capable of inducing different photisms, then a coloured ambiguous grapheme (i.e., pink) that induced a congruently coloured photism (i.e., pink) in the digit context should induce an incongruently coloured photism (i.e., green) in the letter context. If the same form does indeed induce congruent and incongruently coloured photisms depending on the context, then this should have predictable influences on response times – naming the colour of the ambiguous graphemes should be faster in one context (where it induces a congruent photism) than in the other context (where it induces an incongruent photism). Such context dependent patterns of Stroop interference would indicate that the meaning of a grapheme, not the form of a grapheme, determines the colour of a projected photism.

Method

Participant

J is a 22-year old grapheme-colour synaesthete who has experienced photisms when viewing digits and letters for as long as she can remember. She reports that the photisms induced by viewing digits are the same intensity as the photisms induced by viewing letters.

Stimuli

The ambiguous graphemes, as well as the digits and letters that were used as targets are shown in Table I. The targets were presented either in a digit context or in a letter context. In the digit context, either ambiguous graphemes or unambiguous digits were embedded within 5-digit strings. In the letter context, ambiguous graphemes or unambiguous letters were embedded within 4, 5 or 6-letter words. Examples of ambiguous and unambiguous target graphemes in digit and letter contexts are shown in Figure 1. Figure 1 also shows that the graphemes that flanked the targets were presented using different styles of 36-point fonts. When targets were embedded in the letter or digit contexts, all of the graphemes were black and were presented against a light grey background.

Table I shows J's synaesthetic colours for the unambiguous graphemes as well as her synaesthetic colours for both the letter and digit interpretations of each ambiguous grapheme. To determine J's synaesthetic colour for each grapheme, prior to the experiment, she selected a colour for each grapheme from a 256 colour pallet. For each selected colour, J indicted whether the grapheme-colour match was "good", "adequate" or "poor". All grapheme-colour pairs used in the experiment were rated as "good".

Procedure

There were three sessions in the experiment. In the first session, we established a digit context by embedding unambiguous target digits and ambiguous graphemes among digits. In the second session, we established a letter context by embedding unambiguous target letters and ambiguous graphemes among letters. Finally, in the third session, we intermixed the letter and digit contexts from trial to trial by embedding targets among either letters or digits. Each of these sessions was carried out using a Macintosh PowerPC running Psyscope experimental software.

Digit Session

Digit Naming Trials

Prior to completing the Stroop trials, J was presented sequences of unambiguous digits and ambiguous graphemes, and she was asked to name into a microphone the identity of the presented digit as quickly and as accurately as possible. The graphemes were presented in black against a grey background and in random order. On practice trials (n = 16) only unambiguous digits were presented. On test trials (n = 28), unambiguous digits and ambiguous graphemes were presented. These digit naming trials were designed only to establish a

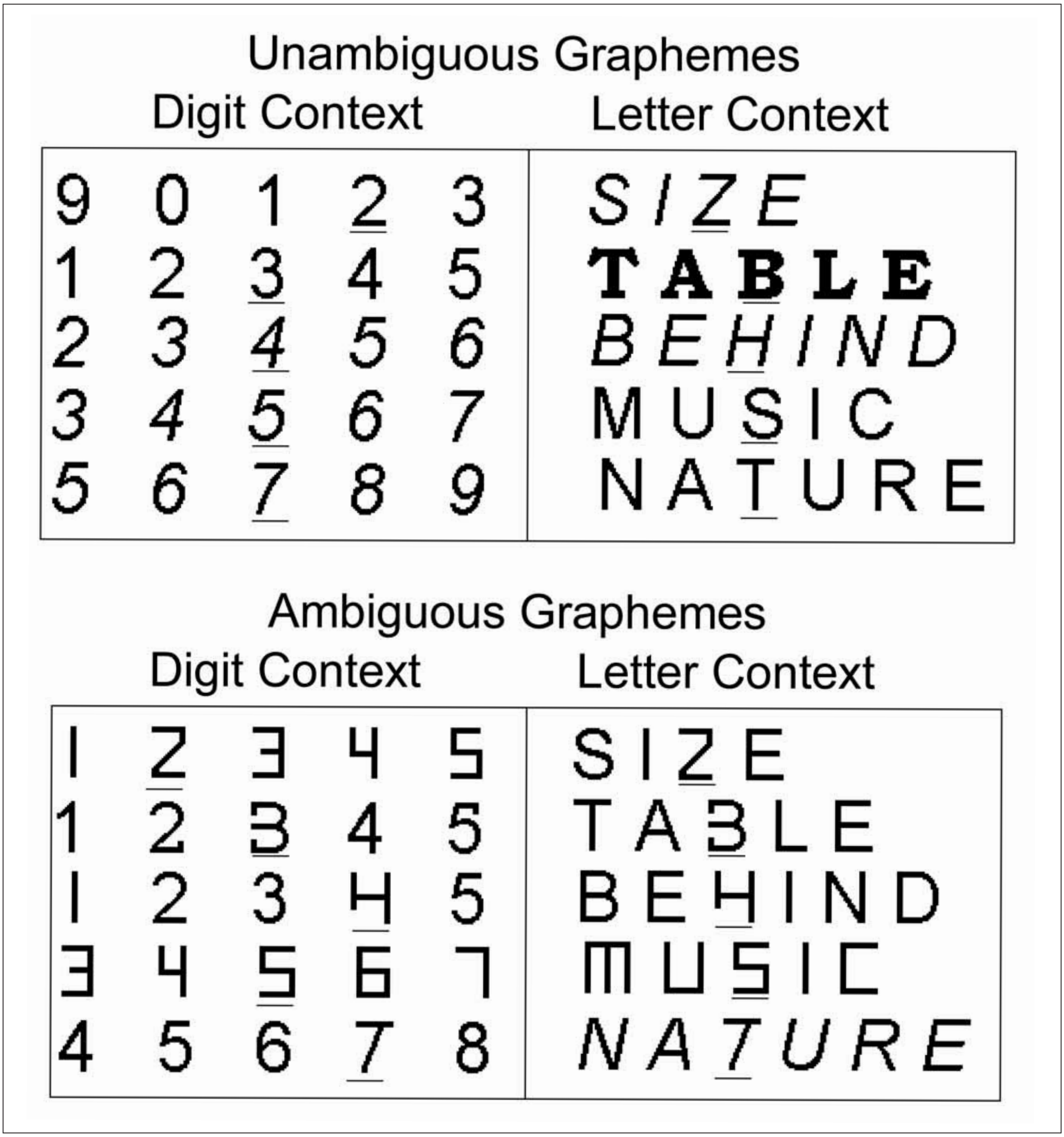

Fig. 1 – *Examples of the digit strings and words used to establish the digit and letter contexts for the unambiguous and ambiguous target graphemes. For purposes of illustration the target graphemes are underlined in the figure but they were not underlined in the actual displays.*

digit context for the ensuing Stroop trials, and to familiarize J with the ambiguous graphemes. The data from these trials were not analyzed.

Digit-context Stroop Trials

On each trial, a five-digit string was presented for one second. Four of the digits were then erased, and the remaining target digit was coloured. J named the colour of this target digit as quickly and as accurately as possible (see Figure 2 for examples of unambiguous and ambiguous digit trials). Unambiguous (n = 150) trials were intermixed with ambiguous (n = 150) trials. For congruent trials, the digit targets 2, 3, 4, 5 and 7 or the ambiguous targets 2, 3, H, 5, 7 were presented in J's colours for the *digits* 2, 3, 4, 5, 7. There were 100 congruent trials (10 for each grapheme). For incongruent trials, the digit targets 2, 3, 4, 5 and 7 or the ambiguous targets 2, 3, H, 5, 7 were presented in the colours for the *letters* Z, B, H, S, and T, respectively. There were 100 incongruent trials (10 for each grapheme). An additional 100 incongruent filler trials were also included to

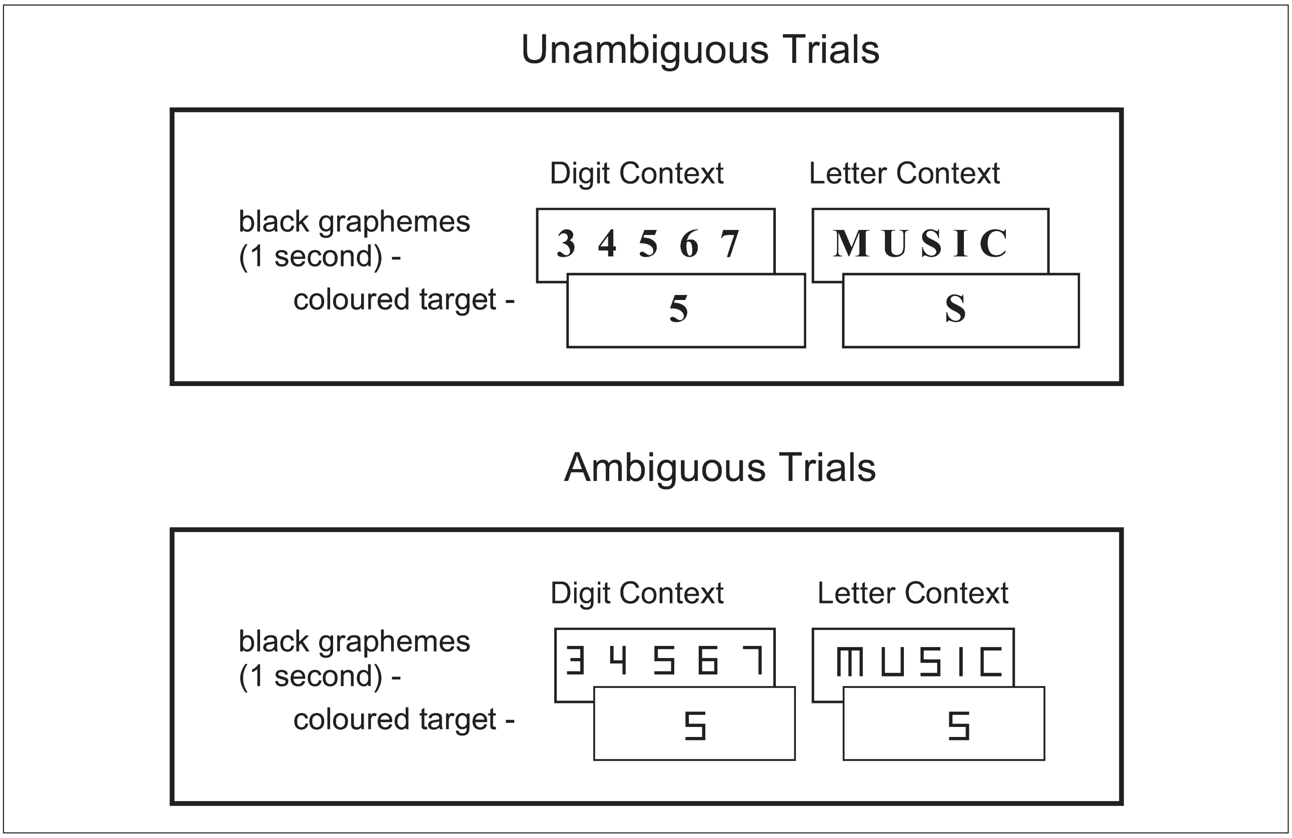

Fig. 2 – *Examples of the sequence of displays used on digit and letter context trials for unambiguous and ambiguous target graphemes.*

minimize congruent trial probability and to reduce strategic influences on colour naming. These incongruent filler trials used incongruent colours other than the key mappings described above and were not analyzed. The 300 "digit context" test trials (150 unambiguous and 150 ambiguous) were preceded by 20 practice trials using only unambiguous digits (10 congruent, 10 incongruent).

Letter Session

Letter Naming Trials

Letter naming trials (similar to the digit naming trials described previously) were presented to establish a letter context for the ensuing Stroop trials and to familiarize J with the ambiguous graphemes.

Letter-context Stroop Trials

Examples of unambiguous and ambiguous letter-context Stroop trials are shown in Figure 2. For congruent trials, the letter targets Z, B, H, S and T or the ambiguous targets 2, 3, H, 5, 7 were presented in J's colours for the *letters* Z, B, H, S and T. There were 100 congruent trials (10 for each grapheme). On incongruent trials, the digit targets Z, B, H, S and T or ambiguous targets 2, 3, H, 5, 7 were presented in the colours for the *digits* 2, 3, 4, 5 and 7, respectively. There were 100 incongruent trials (10 for each grapheme). An additional 100 incongruent filler trials were included to minimize congruent trial probability and to reduce strategic influences on colour naming. The 300 "letter context" test trials (150 unambiguous, 150 ambiguous) were preceded by 20 practice trials using only unambiguous letters (10 congruent, 10 incongruent).

Intermixed Session

In this final session, the Stroop trials were repeated with the exception that digit context and letter context trials were intermixed instead of blocked. The 600 intermixed test trials were preceded by 40 practice trials consisting of 10 congruent digit targets, 10 incongruent unambiguous digit targets, 10 congruent letter targets and 10 incongruent unambiguous letter targets.

Results and Discussion

Response Times

Only the response times for the ambiguous graphemes were analyzed. Response times that were more than 3 standard deviations from the mean response time for each condition were considered outliers and were not analyzed. The remaining

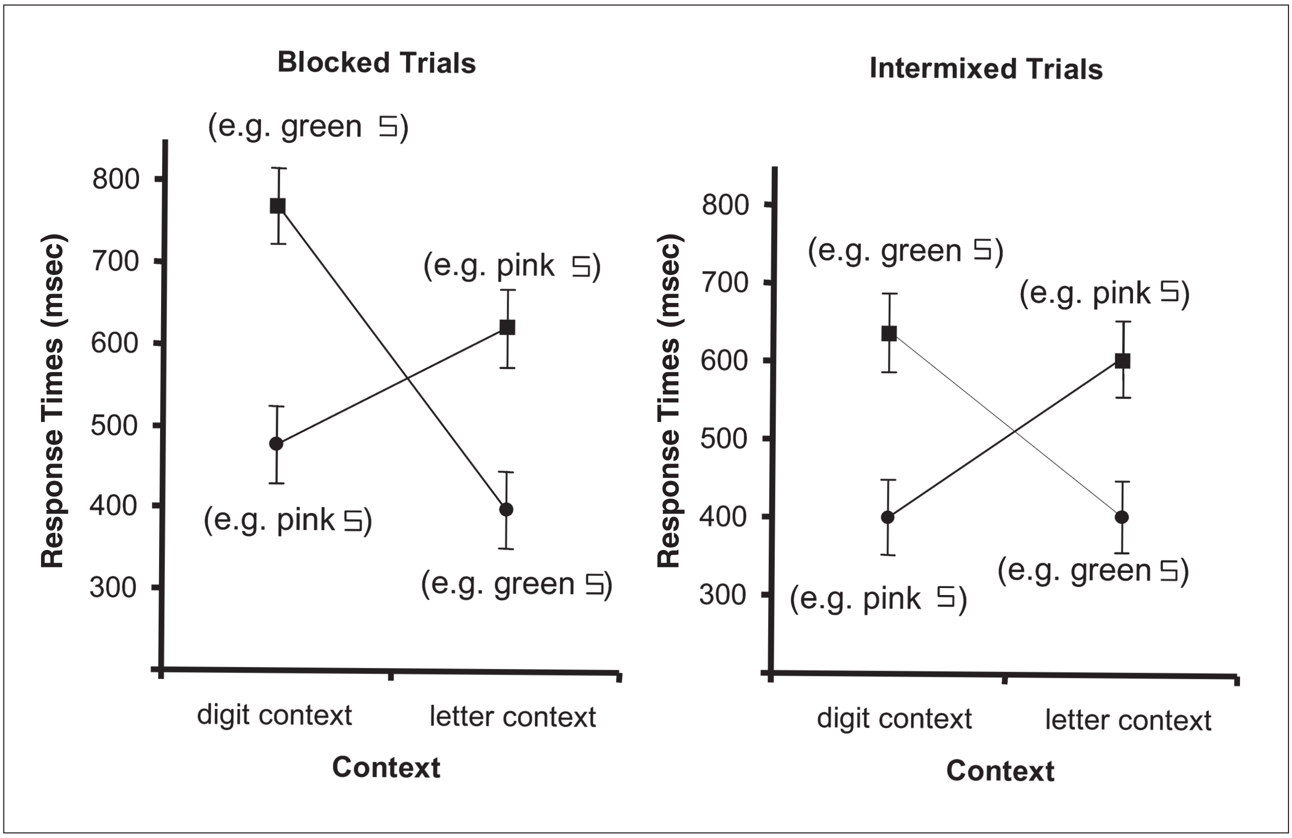

Fig. 3 – *Mean response times (and 95% confidence intervals) for naming the colour of ambiguous graphemes in the digit and letter sessions (left side) as well as the intermixed session (right side). Congruent trials are depicted by circles, incongruent trials by squares. Lines join conditions where J named the colours of visually identical graphemes.*

response times in the digit, letter and intermixed sessions were analyzed using (Bonferroni corrected) planned comparison t-tests. All comparisons reported below were significant at or beyond $p < .001$.

J's average response times for naming colours of ambiguous graphemes in the digit and letter sessions are presented in the left panel of Figure 3. When Z, 3, H, 5, 7 were embedded in digit strings and were displayed in J's colours for 2, 3, 4, 5 and 7, her response times were significantly faster than when these same graphemes were presented in J's colours for Z, B, H, S and T. When Z, 3, H, 5, 7 were embedded in words and were displayed in J's colours for Z, B, H, S and T, her response times were significantly faster than when these same graphemes were presented in J's colours for 2, 3, 4, 5, 7. These large context-dependent Stroop effects for the ambiguous graphemes interpreted as digits and letters can be seen by looking at the large separation between the congruent trial means (the circles in Figure 3), and the incongruent trial means (the squares in Figure 3).

The crucial data are the contrasts depicted by the lines in the left panel of Figure 3. The lines join conditions where J named the colours of the exact same stimuli (e.g., a pink 5 that served as a congruent trial in the digit context served as an incongruent trial in the letter context). The X shape formed by these lines indicates that the exact same forms induced differently coloured photisms. For example, in the digit context, a pink 5 induced a pink photism that facilitated colour naming times. In the letter context, the same pink 5 induced a green photism which slowed colour naming times (this contrast forms the ascending arm of the X shape). Completing the X shaped pattern, in the digit context, a green 5 (for example) induced a pink photism, leading to slow response times but in the letter context, the same green 5 induced a green photism, leading to fast response times (this contrast forms the descending arm of the X shape). In sum, the X-shaped pattern indicates that *identical* graphemes induced differently coloured photisms depending on whether they were interpreted as digits or letters.

In the intermixed session (shown on the right side of Figure 3), the same X-shaped pattern emerged indicating that these context dependent Stroop effects were both robust and reliable. Figure 4 shows separate analyses of J's colour naming response times for the five different ambiguous graphemes in the intermixed session. All five graphemes elicited the X-shaped pattern of means. Thus, unlike the Myles et al. (2003) study, each ambiguous grapheme induced differently coloured photisms, depending on its interpretation. Thus, the results of the intermixed session replicate the results of the digit and letter sessions. The findings

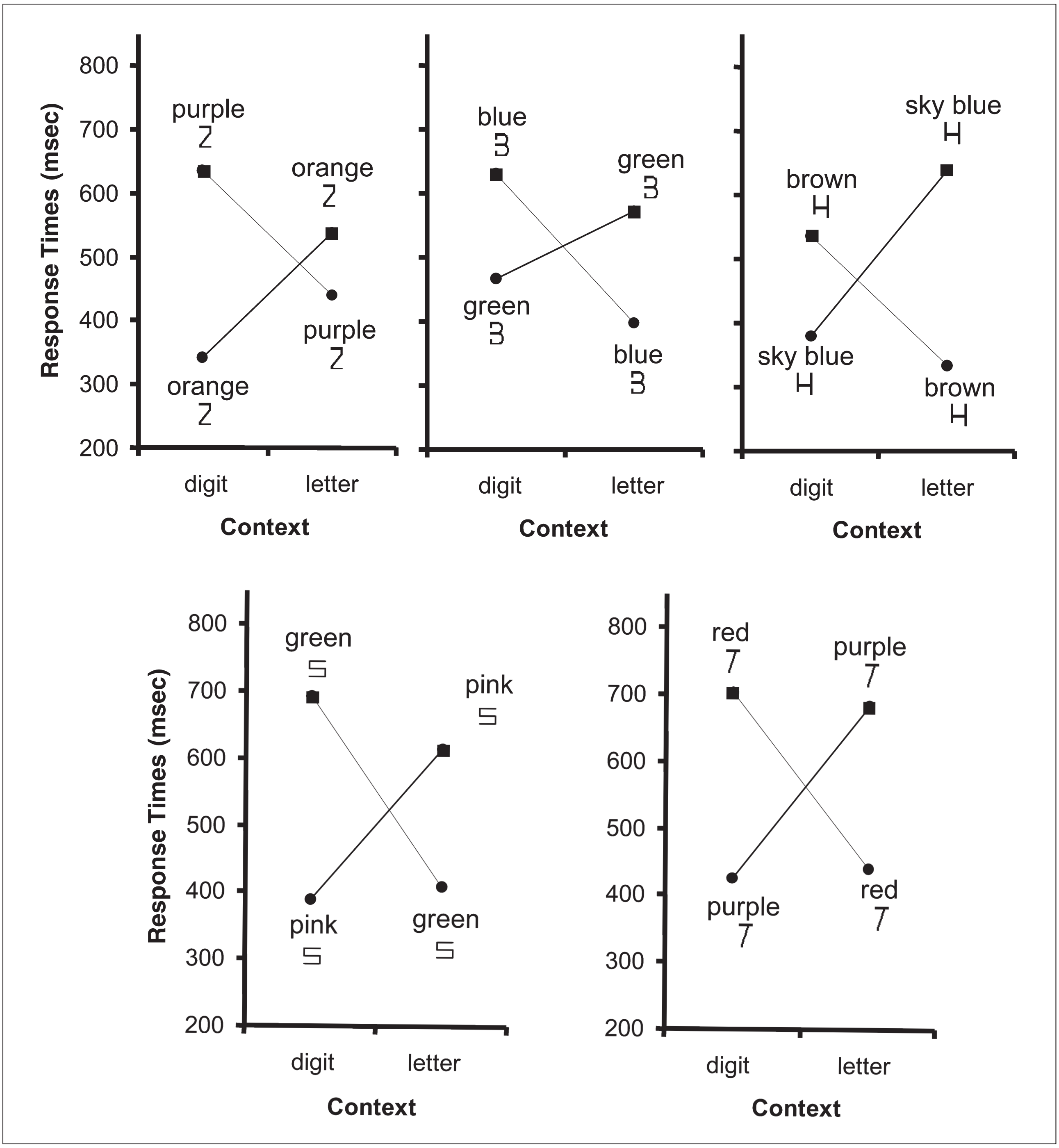

Fig. 4 – *Mean response times for naming the colours carried by each of five different ambiguous graphemes in the intermixed session. Congruent trials are depicted by circles, incongruent trials are squares. Lines join conditions where J named the colours of visually identical graphemes.*

clearly indicate that the same ambiguous graphemic form can induce two differently coloured photisms depending on whether the grapheme is interpreted as a digit or as a letter. As such, the findings imply that grapheme meaning plays a critical role in determining the colours of synaesthetic photisms.

Errors

Although J made too few errors to be statistically analyzed, her error patterns indicate that the response-time analyses reported below are not compromised by any speed-accuracy trade-offs. J's error rates for the digit, letter and intermixed sessions are shown in Table II.

General Discussion

The purpose of the present experiment was to evaluate whether projected synaesthetic colours depend primarily on the meaning of graphemes or

TABLE II

Percent errors for naming the colours of ambiguous graphemes presented in digit and letter contexts

	Digit context		Letter context	
Congruency	Blocked	Intermixed	Blocked	Intermixed
Incongruent	0%	0%	6%	2%
Congruent	2%	2%	4%	2%

whether they depend primarily on the visual form of graphemes. J, a projector grapheme-colour synaesthete, was required to name the colour of ambiguous graphemes that she was induced to think of as either digits or letters, according to the context they were presented in. The colour that J had to name was either congruent or incongruent with J's interpretation of the grapheme. To ensure that strategic effects on colour naming did not compromise the findings, there were twice as many incongruent trials as congruent trials in the experiment. Given the low congruent trial probability, the best "strategy" was to follow the instructions and to attempt to name the colour of the target as quickly and as accurately as possible. Under these conditions, J showed large context-dependent Stroop effects indicating that each ambiguous grapheme induced differently coloured photisms depending on whether it was interpreted as a digit or letter. The findings clearly indicate that synaesthetic colours depend primarily on the meanings assigned to graphemes rather than the particular forms of the graphemes.

The present findings extend previous context-dependent Stroop effects reported by Myles et al. (2003) in several important ways. First, the present findings go a long way to establishing the generality of the previous findings; we found context-dependent Stroop effects similar to those reported by Myles et al. (2003) with a different synaesthete. Second, unlike the study of Myles et al. (2003) which only showed influences of context for two out of three graphemes, here we found large context-induced Stroop effects for each of the five ambiguous graphemes that we tested. Third, by showing large context-induced Stroop effects using different modes of presentation (context blocked *vs*. intermixed presentations) we were able to demonstrate the robustness and reliability of these findings. One possible reason why the context-induced Stroop effects were stronger and more reliable in the present study than in the Myles et al. (2003) study is that the present experiment involved a more salient manipulation of conceptual context. In the Myles et al. (2003) study, the conceptual context for an ambiguous grapheme was established by the identity of graphemes on previous trials. In contrast, in the present study, the conceptual context was established on each trial by directly embedding the ambiguous grapheme within a string of digits or letters.

The present findings have important implications for models of grapheme-colour synaesthesia. In order to understand these implications, it is important to distinguish between two different types of synaesthetes: "projectors" and "associators". As noted above, projector synaesthetes experience their synaesthetic colours as overlays that sit atop the visually presented graphemes, whereas associator synaesthetes experience their synaesthetic colours in their mind's eye. Ramachandran and Hubbard (2001b) use different terminology to convey essentially the same distinction: they refer to projector synaesthetes as "lower" synaesthetes and to associator synaesthetes as 'higher' synaesthetes. This distinction between lower/projector and higher/associator synaesthetes is important because Ramachandran and Hubbard have proposed different cross-activation models to account for the experiences of lower and higher synaesthetes. In Ramachandran and Hubbard's account, there are abnormal connections between adjacent areas of cortex. The key difference between lower and higher synaesthetes is where these abnormal connections occur. Lower synaesthetes have abnormal connections between areas of the fusiform that process graphemic form and areas of the fusiform that involve the perception of colour (e.g., V4 or V8). Higher synaesthetes have abnormal connections between later stage areas involving the concepts of graphemes and "higher color areas" (Ramachandran and Hubbard, 2003).

The finding that the same ambiguous grapheme can induce different photisms has different implications for higher and lower synaesthetes. Consider first higher synaesthetes (i.e., associator synaesthetes). Informal tests in our laboratory reveal that like projector synaesthetes, associator synaesthetes also experience different coloured photisms when they interpret ambiguous graphemes as either digits or letters. For higher synaesthetes, 5 for example activates the concept of either 5 or S, depending on the context. If the concept of 5 is activated, the colour associated with 5 is also activated, whereas if the concept of S is activated, the colour associated with S is activated. Thus the cross-activations between later stage areas involving the concepts of graphemes and areas that process the conceptual aspects of colour can easily explain how the same form (e.g., a 5) triggers differently coloured photisms.

Now consider lower synaesthetes (i.e., projector synaesthetes) such as J, the synaesthete tested in the present study, and PD, the synaesthete tested in the Myles et al. (2003) study. In order to account for projected photisms, Ramachandran and Hubbard (2001a, 2001b, 2003) proposed that areas of the fusiform gyrus dealing with graphemic form are cross-linked to the fusiform areas that process colour. Crucially, these cross-linkages occur prior to areas associated with the meaning of graphemes. In such an architecture, it is difficult to see how the same grapheme can elicit two different synaesthetic colours. To account for the present findings, cross-linkage models would have to include a formal mechanism for feedback from areas involved in processing the identity or meaning of a grapheme, and areas involved in processing the form of the grapheme.

An alternative model to the cross-talk model has been suggested by both Grossenbacher and Lovelace (2001) and our research group (Smilek et al., 2001; Smilek and Dixon, 2002; Dixon, et al., 2004a). This alternative model involves direct feedback from areas of the brain that process meaning to areas of the brain that process colour. When we first postulated a feedback-based architecture where form is linked to meaning and meaning is then linked back to colour along feedback pathways (Smilek et al., 2001), we suggested that a grapheme can elicit different colours depending on whether it is interpreted as a digit or as a letter. The present findings provide strong empirical evidence for such top-down context effects.

We would be remiss if we did not acknowledge that Ramachandran and Hubbard (2001b) recognized that top-down influences can influence synaesthetic experiences. In fact, they have even provided some informal demonstrations of how context can ultimately determine the colour of photisms (Ramachandran and Hubbard, 2001b). Nevertheless, they ultimately imply that for lower (i.e., projector) synaesthetes, it is the forms of the graphemes that are primarily responsible for determining the synaesthetic colours. They conclude that "their experiments demonstrate that synaesthesia can also be strongly modulated by top-down influences. However, this should not be taken to imply that grapheme-colour synaesthesia is a conceptual phenomenon. Instead, it merely indicates that, like many other perceptual phenomena such as the famous Rubin face-vase or the Dalmatian, cognitive influences can also influence early sensory processing" (Ramachandran and Hubbard, 2001b).

In justifying why they choose to minimize the importance of meaning in grapheme-colour synaesthesia, Ramachandran and Hubbard (2001a, 2001b) invoke several findings. They reported that when graphemes were presented eccentrically (beyond 11 degrees of visual angle) although their synaesthetes could identify the graphemes they no longer experienced photisms. Similarly, they reported that when two graphemes were alternately presented in the same location and the alternation was at high speeds, although each grapheme could still be identified, their synaesthetes did not experience photisms. Ramachandran and Hubbard (2001a, 2001b) conclude that since meaning is activated, (i.e., graphemes can be identified) yet no photisms ensue, meaning plays little role in producing photisms. Crucially, however the *forms* of the graphemes in these demonstrations are also perceived (yet no photisms are experienced). It is unclear to us why the logic of these experiments is sufficient to minimize the role of meaning, yet this same logic leaves the role of graphemic form untouched. An alternative interpretation of these demonstrations is that if graphemes are presented in unusual circumstances, they may fail to engage a re-entrant circuit involving graphemic form, graphemic meaning and synaesthetic colour – a circuit that would automatically be engaged by viewing graphemes under standard conditions.

To summarize, it seems that the main difference between cross-activation and feedback accounts of projected synaesthetic photisms is the relative importance of the role of meaning and form in determining synaesthetic photisms. For the cross-activation model, even though meaning can determine the colour of photisms, it does so only in special cases. More typically, it is the form of the grapheme that is crucial in triggering photisms. For feedback accounts, the default position is that it is the meaning of a grapheme and not the form of a grapheme that determines the colour of a photism – a finding that is consistent with the evidence presented here showing that the exact same form can generate two differently coloured photisms depending on its interpretation.

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