Neurocase (2006) **12**, 27–34

ISSN: 1355-4795 print
DOI: 10.1080/13554790500473672

Psychology Press
Taylor & Francis Group

Synaesthesia for Reading and Playing Musical Notes

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This study reports three cases of synaesthesia who experience colors in response to written musical notation, graphemes and heard music. The synaesthetes show Stroop-like interference when asked to name the colour of graphemes but not for written musical notes. However, reliable interference is found in two further studies that require deeper processing of the musical notation (namely playing music from colored notation, and naming the synaesthetic color of the notes whilst suppressing the veridical color). This is the first empirical demonstration of synaesthesia for musical notation. The fact that synaesthetic color influences music playing/reading (a sensory-motor transformation) but not verbal color naming suggests that synaesthetic Stroop effects can arise from processing the meaning of a stimulus and not just as a result of verbal response interference. However, it is likely that the color associations themselves have a developmental origin in the names assigned to them. In all three cases, the colors of the written notes are related to the graphemes that arbitrarily denote them (e.g., 'A' may be "red" both as a letter and when written in musical notation). The results suggest that synaesthetic associations may migrate from one representational format (e.g., graphemes) to another (e.g., musical notation).

Introduction

Synaesthesia is a condition in which perceptual experiences are elicited by stimuli that are not normally associated with such an experience (for a review see Ward and Mattingley, 2006). In the developmental form, it runs in families and is reported to exist throughout the lifespan (Ward and Simner, 2005). It is associated with anomalous patterns of brain activity, consistent with it being a perceptual phenomenon (e.g., Nunn *et al*., 2002). However, it is not considered harmful or disruptive for cognition in general. Color is, by far, the most common form of synaesthetic experience (Simner *et al*., in press), although synaesthesia involving other modalities is found (e.g., Ward *et al*., 2005). In terms of stimuli that induce synaesthesia, the most common inducers are letters, numbers and words (particularly the names of days and months) (Simner *et al*., in press). The present study is the first demonstration of synaesthesia involving written musical notation, in which notes on the musical stave trigger perceptual experiences of colour.

Day (2005) reports that 10.8% of synaesthetes in a large self-referred sample report colors with written musical notes, compared to 68.8% for colored graphemes and 18.5% for colored musical sounds. However, to date, no systematic study has been carried out on this variety of synaesthesia. The purpose of our study is not merely to document yet another variety of synaesthesia. Nor is it our purpose to make claims about colored musical notation in particular. Rather, what we hope to show is that this particular variety of synaesthesia can provide general constraints concerning the origins and development of synaesthesia. In particular, we demonstrate how synaesthesia may be linked to conceptual rather than perceptual processing of the inducing stimulus[1]. Moreover, we demonstrate that synaesthesia may 'leak' from one system of representation to another. Thus, colors associated with letters may become associated with notes. This is consistent with the emerging view that synaesthetic associations can be biased by experience (e.g., Ward and Simner, 2003; Rich *et al*., 2005; Witthoft and Winawer, 2006) and does not reflect *just* hardwired connections left over from the earliest phases of development (although these may still be important).

A number of recent studies of bilingual synaesthetes have demonstrated that synaesthetic associations can migrate from one alphabetic system to another. Mills *et al*. (2002) reported a multi-lingual synaesthete who was a native English speaker but had learned Russian to a fluent level from high school. If a letter was the same or similar in shape between Roman and Cyrillic (including mirror reversals) then the same color was associated with both. This occurred even if the letter represents different phonemes in the script (on 9/12 occasions; e.g., B is /b/ in English and /v/ in Russian). For Cyrillic letters that have no visual resemblance to a Roman letter but represent a phoneme that occurs in English, then the color tended to resemble the color of the Roman grapheme (on 6/8 occasions; e.g., P and П are both pronounced as /p/). Witthoft and Winawer (2006) report a very similar pattern in a native

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[1] This is not to be confused with the nature of the synaesthetic experience itself that is necessarily perceptual (according to the definition offered here). It is an open question as to whether synaesthesia is induced by perceptual properties of the stimulus (e.g., the font) the conceptual properties (e.g., the inferred meaning) or both (e.g. Dixon *et al*., in press; Grossenbacher and Lovelace, 2001).

English speaker who moved to Russia at 3 years of age, and Rich *et al*. (2005) report a similar pattern in a native English speaker who learned Greek as an adult. These studies suggest that graphemes from scripts learned later in life can obtain synaesthetic colors from graphemes in early acquired scripts and that they do so in a systematic way. Our study extends these findings by demonstrating that colors can also migrate between graphemes and a completely different representational system—namely musical notation. Most musical notes bear no obvious visual resemblance to letters of the Roman alphabet although, in English, the notes in an octave happen to be named after the letters A to G.

One central debate in the synaesthesia literature concerns the extent to which synaesthetic experiences are induced by perceptual properties of a stimulus versus conceptual properties. In the domain of grapheme-color synaesthesia, changes in font can affect the saturation of the colors perceived (e.g., Witthoft and Winawer, 2006). However, the color itself tends to be largely determined by the identity of a grapheme. Thus, upper case and lower case letters typically have the same color even when they are visually dissimilar (e.g., 'A' and 'a'). Moreover, ambiguous graphemes tend to take on the color appropriate to their context. For example, a stimulus that can be interpreted as either 'S' or '5' will take on the color associated with the letter if presented in a context such as MU_IC but may take on the color associated with the numeral if presented in a context such as 34_67 (e.g., Myles *et al*., 2003; Dixon *et al*., 2006). Our study extends these findings to the domain of written musical notation. Reading of a musical note is heavily context dependent. For example, a note printed in the center of a stave is entirely ambiguous as to its identity unless it is provided within a wider context: when interpreted as lying in the bass clef the note corresponds to D but when interpreted as lying in the treble clef it corresponds to B.

Reading music also differs from reading text in another important way. Reading music essentially involves a sensory-motor transformation between a visuo-spatial code (the sequence of notes written on the stave) and a manual output (the position of the fingers on keyboards, frets, or holes) (e.g., Stewart *et al*., 2003). Our study demonstrates that playing of musical notes is biased if the notes are printed in synaesthetically incongruent colors. Thus, synaesthetic Stroop effects can be found in sensory-motor acts and are not restricted to conditions in which a color name is given as a response. The latter can be explained according to simple response competition between two verbal color names but the former cannot be explained in this way.

Our first two experiments are variants of the standard synaesthetic Stroop effect in which musical notes are printed in colors that are either congruent or incongruent with their synaesthesia. The notes were presented in either the bass or treble clef. For comparison, we report similar experiments using the graphemes A to G and also by coloring in the white keys on a keyboard octave (the synaesthetes also report color sensations when attending to the keys on a keyboard).

Case Descriptions

In this study, we document three different cases of synaesthesia (LHM, RT and MM). Each case is analyzed and reported separately, although the similarities between them far outweigh the differences. The background details of the three cases are reported in Table 1. All three cases have a high degree of musical aptitude and are skilled at reading music. None of them report perfect pitch (i.e., the ability to identify a heard note without a reference point)[2]. Their synaesthesia for numbers (N = 10), letters (N = 26), days/months (N = 7 + 12) and, when appropriate, other words (N = 80) was assessed using a measure of internal consistency. All synaesthetes were highly consistent over a 2–4 month interval relative to a group of controls (N = 43) with a two-week retest (see Table 1). Controls were asked to free associate a color to each item. Other tests supporting the authenticity of their synaesthesia are reported later.

As with their synaesthesia for verbal material, their reports of color sensations to musical notes were stable over an 18 month period. These are documented in Table 2 and are compared to the color sensations reported for the letters A to G. There was a close correspondence between the colors of the musical notes and those of the graphemes (e.g., for participant MM, both the letter F and the note F are bluey mauve). The basic color of the notes repeated cyclically on the stave, although they were not identical. For example, all written 'A' notes may be red, but the shade of red may differ somewhat depending on its position on the stave. In contrast, there was no obvious relationship between the color of written musical notes and the color associated with their corresponding heard piano notes (played in the middle C octave, and unlabelled)[3]. A full description of LHM's sound-color synaesthesia can be found elsewhere (Ward *et al*., 2006).

For RT, the colors for 6 out of 7 notes in the octave are the same (or very similar) to the colors for the letters A to G. The one exception to this is the musical note 'A'. This is green when written on the stave but red as a grapheme. We can only speculate as to why this might be: 'A' follows 'G' musically but 'H' follows 'G' alphabetically (the grapheme 'H' has the same color as the musical note 'A'). Not only are notes on the stave colored but the key signature is colored too. For example, the written key signature for D-major (F#, C#) takes on the colors yellow and red (F is yellow and C is red).

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[2] When given 11 piano notes from 1 octave either side of middle C in a random order, neither LHM nor MM were able to guess the identity of the note any more than would be expected by chance (18% and 27% respectively). RT was unavailable for testing on this occasion. She is certain that she is unable to identify isolated notes.

[3] RT was not tested with auditory notes (she lost contact with the researchers), but our main claims concern the similarities between graphemes and written musical notes (that we were able to verify on several occasions).

Table 1. A summary of the background details and characteristics of the three synaesthetes studied

	LHM	RT	MM
Age and sex	Female, 26 years	Female, 22 years	Female, 47 years
Handedness	Right-handed	Right-handed	Right-handed
Musical background[1]	Learned music from age 3. Piano and singing (grade 7), trombone (grade 5).	Learned music from 4 years. Flute and singing (grade 8) and has also learned piano and viola (but not taken formal grades for these instruments).	Learned music from 8 years. Professional opera singer and voice coach. Degree and postgraduate qualifications in music. Piano, violin and singing (all to grade 8).
Types of synaesthesia[2]	Musical notation-color; graphemes-color; sound-color; words-color; taste-color; smell-color	Musical notation-color; graphemes-color; sound-color; many other types reported involving aspects of touch, taste, smell, vision and sound	Musical notation-color; graphemes-color; sound-color; words-color; pain/touch-color
Internal consistency (relative to control sample scores)	91% (Z = 4.31, P < .001)	98% (Z = 4.53, P < .001)	100% (Z = 4.67, P < .001)

Note. [1]Grade 8 is the highest in the British system of musical grades. This level is expected around the age of 18 following between 8 to 10 years of learning. [2]The distinction between sound-color and word-color is motivated by the fact that, in the case of sound-color it is acoustic properties (pitch, timbre) of the stimulus that appears relevant whereas in word-color it is linguistic properties (e.g., the spelling) that appears relevant.

Table 2. The colors of the letters A to G, the colors of the corresponding notes when written on the stave, and the colors of the heard notes when played on the piano (where 'C' is the lowest pitch and other notes are from the middle-C octave).

	LHM			RT		MM		
	Letter	Notes	Sound	Letter	Notes	Letter	Notes	Sound
C	Blue with purple	Blue with purple	Browny burgundy	Red	Red	Straw yellow	White	Brown
D	Brown	Brown	Reddish	Blue	Blue	Brown	Brown	Orange
E	Turquoise pale	Yellow	Reddy	Yellow	Yellow	Yellowy green	Yellowy green	Brown
F	Light green	Light green	Reddy	Yellowy green	Yellowy green	Bluey mauve	Bluey mauve	Orange
G	Dark green	Dark green	Light red, orangey	Brown	Brown	Orange	Orange	White
A	Red	Red	Orangey	Red	Green	Red	Red	Red
B	Pale blue	Pale blue	Yellowy	Blue	Blue	Deep yellow	Deep yellow	Yellow

Experimental Investigation

Experiment 1: Stroop Interference for Written Music, Letters and the Keyboard

Method

For each of the synaesthetes, four sets of stimuli were used. These comprised colored musical notes (crotchets) in the treble or bass clef, colored keyboard keys, or colored graphemes. The staves and the keyboard measured 13 cm across (participants were sat at a distance of 60 cm). Each set of stimuli used the seven notes, keys or graphemes from A through to G. Each synaesthete had been asked to select the closest color to represent her synaesthetic photism for that stimulus. Incongruent pairings were created by using this same set of colors but assigning them to different stimuli. The 7 congruent and 7 incongruent stimuli were presented 6 times in each set in a pseudo-random order (such that the same color never appeared in consecutive trials). Thus, there were 84 trials in each set.

Each participant was given practice (with feedback) at naming the colors for 14 trials prior to the main experiment. Each stimulus was preceded by a filled interval of 1000 msec. For the graphemes, this consisted of a central fixation cross. For the musical notes, it consisted of a blank stave. For the keyboard, it consisted of a blank keyboard. Examples of the stimuli used are shown in Figure 1. Following the 1000 msec the colored stimulus appeared on the screen and remained until the participant responded. Participants responded by naming the (veridical) color of the stimulus as quickly and accurately as possible into a microphone.

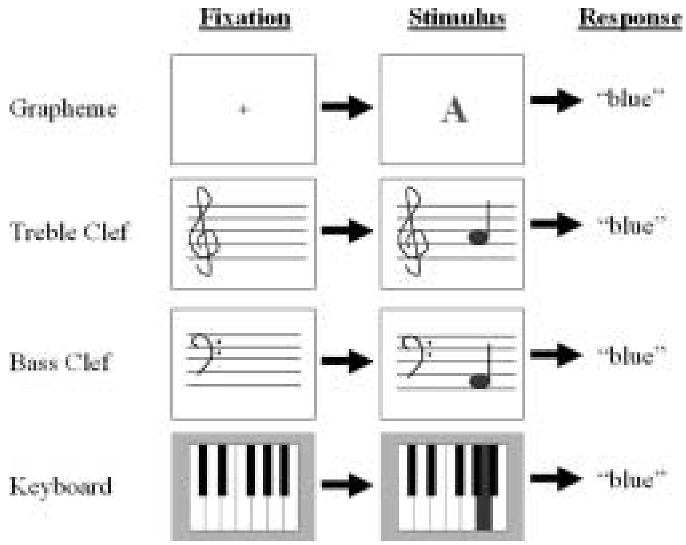

Fig. 1. Examples of the four different conditions used in Experiment 1. All these stimuli are graphemic and musical representations of 'A'. Participants were required to name the colour of the stimulus and ignore their synaesthetic colour (e.g., "blue"; depicted here in grey).

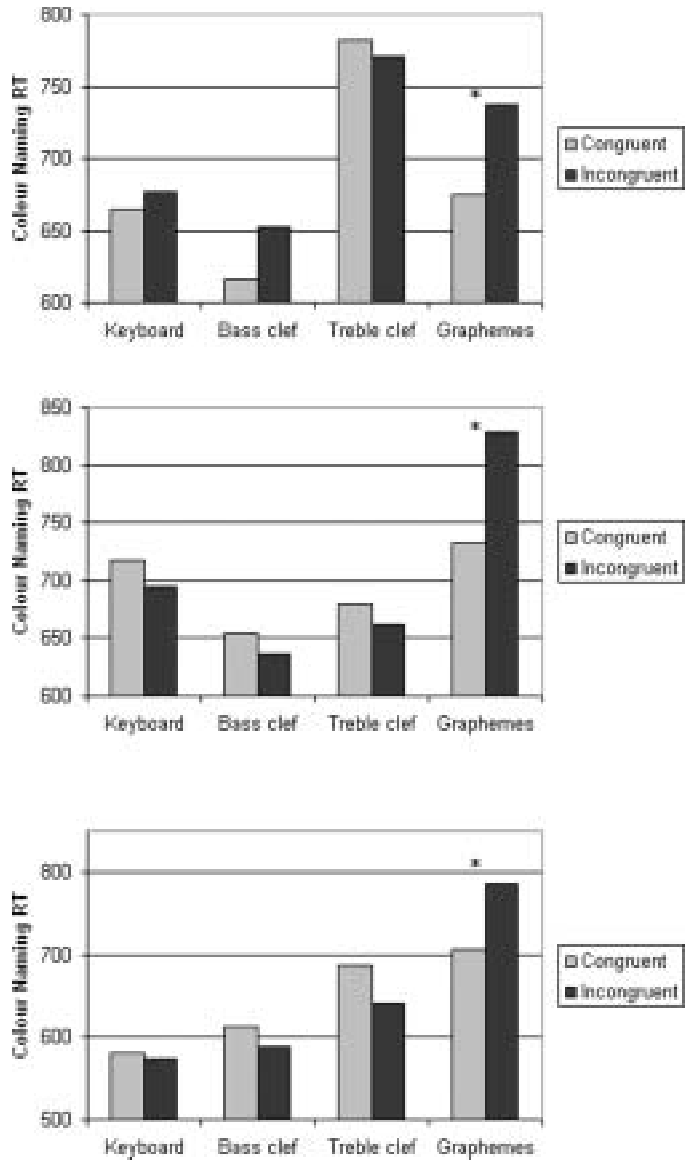

Fig. 2. Stroop interference is found for graphemes but not for naming the colour of notes (response time, RT, in msec) in the treble or bass clef or for keys on the keyboard (from top to bottom the data are from MM, LHM and RT). [* $P < .05$]

Results and Discussion

The results for the three synaesthetes are summarized in Figure 2. In this and all subsequent experiments, error trials were infrequent and were excluded from response time analysis. Case MM showed significant Stroop interference in the grapheme condition ($t(82) = 2.02$, $P < .05$) as did LHM ($t(79) = 2.33$, $P < .05$) and RT ($t(35) = 3.24$, $P < .05$). None of the other conditions approached significance.

In summary, whilst we found evidence that letters reliably elicit synaesthetic colors, we could find no evidence that musical stimuli elicit synaesthetic colors—contrary to the subjective reports of the synaesthetes. This can be interpreted in several ways: the synaesthetes are disingenuous about their synaesthesia for musical notation; or the task characteristics were not sensitive to this variety of synaesthesia; or the synaesthetes employed some strategy that suppressed their synaesthesia. It seems implausible to us that they would mislead us about one type of synaesthesia (musical notation-color) but be honest about another type (grapheme-color). Whilst we cannot have third-person access to their experiences, we can alter the parameters of the task to maximize the chance of detecting an influence of their synaesthetic color. This was done in Experiment 2.

Experiment 2: Stroop Interference for Written Music with Delayed Presentation

This experiment was identical to the treble and bass clef conditions in Experiment 1 except for the fact that there was a delay between the onset of the note and the onset of the color of that note. We hypothesized that synaesthesia may take longer to appear for musical notation than for graphemes because musical notation is likely to be less familiar even to the musically trained. Thus, presenting the note in black for a brief duration before presenting the color may facilitate more detailed processing of the stimulus prior to commencing color naming.

Method

The procedure was identical to that used in Experiment 1 except in one important respect. There was a 150 msec delay after the fixation during which the note was presented in black. After the 150 msec, the color of the note changed to either the congruent or incongruent color to which a speeded naming response was required. Thus, the identity of the note precedes the color. This procedure was only used for the treble and bass clef musical notes. The grapheme condition was excluded because this has already been shown to be genuine.

Results and Discussion

Only one of our three synaesthetes showed the expected Stroop interference in this experiment. MM was significantly slower at naming incongruent colors both in the treble clef (congruent = 622 ms, incongruent = 830 ms; $t(42) = 3.67$, $P < .001$) and the bass clef (congruent = 606 ms, incongruent = 723 ms; $t(41) = 3.25$, $P < .001$). It is to be noted that MM also has the most extensive musical training. For LHM, there was no significant interference of incongruent relative to congruent colors in naming the color of bass notes (congruent = 679 msec, incongruent = 717 msec; $t(77) = 1.45$, N.S.) or treble notes (congruent = 594 msec, incongruent = 591 msec; $t(80) = .18$, N.S.). For RT, there was a borderline significant interference of incongruent relative to congruent colors in naming the color of bass notes (congruent = 784 msec, incongruent = 849 msec; $t(38) = 1.96$, $p = .057$). There was no significant interference in naming the color of the treble notes (congruent = 729 msec, incongruent = 717 msec; $t(39) = .51$, N.S.).

Unlike previous demonstrations of the Stroop effect in synaesthesia, we have had (thus far) somewhat limited success in extending these results to reports of colored musical notation. It is conceivable that either (a) this type of synaesthesia is not genuine (b) it is genuine but works differently from other types of synaesthesia (c) the participants employed some strategy that suppressed their synaesthesia. LHM and RT did provide some comments consistent with the latter. The identity of the note is determined by vertical position on the stave and the clef in which it is written. This differs from grapheme identity that is determined by the shape (at least when the shape is unambiguous). Our synaesthetes deliberately tried not to identify the note so that they could just process the color. This could be achieved by, for example, neglecting the clef and just concentrating on part of the note (e.g., the stem). The fact that the notes were unusually large (6 cm in height) may have helped such strategies. The remaining two experiments required participants to focus on the identity of the note, also under Stroop conditions. In such situations, reliable interference from incongruent colors is indeed found across all three synaesthetes.

Experiment 3: Stroop Interference for Playing Music

In this experiment, the synaesthetes were asked to silently play colored notes using a five-fingered keyboard. In contrast to the Stroop experiments already described, the task requires the participants to process the note and ignore the color rather than process the color and ignore the note.

Method

The stimuli consisted of two sets of 5 notes: E to B in the treble clef and A to E in the bass clef. The treble clef stimuli and the bass clef stimuli were divided into two blocks. Each block consisted of 60 stimuli—30 congruent trials and 30 incongruent trials. The incongruent trials were formed by re-assigning the colors and notes used in the congruent trials. The trials were randomly ordered, and preceded by 15 practice trials containing black notes only. The participant placed a hand over 5 buttons on a serial response box that served as a mock keyboard. They were told which buttons corresponded to each note. There were four blocks for each participant in which the clef (bass vs. treble) and hand (left vs. right) were orthogonally contrasted. There was a 1000 msec fixation that consisted of a blank musical stave as in the previous experiments. This was followed by a colored note that remained on the screen until a finger press was made. Unlike playing a real piano or keyboard there was no resulting sound and, as such, the experiment involves silent music playing.

Results and Discussion

The results are summarized in Figure 3. There was a reliable interference effect of presenting notes in synaesthetically incongruent colors if each of the 12 blocks is treated as a separate measure ($t(11) = 3.31$, $P < .01$). Analyzing each of the blocks separately there were 8 blocks that reached significance (LHM: bass with left and right hand; RT: bass and treble with right hand; MM: all conditions) and a further 3 blocks showed a nonsignificant trend in the expected direction. Those conditions reaching significance were drawn from a mix of clefs, hands and synaesthetes[4]. We can only assume that the task itself is quite noisy because, for instance,

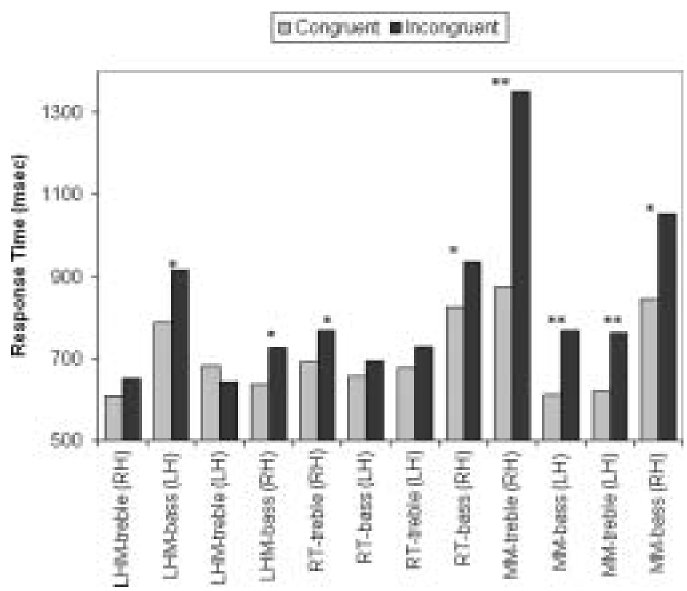

Fig. 3. Stroop interference is found when synaesthetes are asked to play coloured notes [* $P < .05$, ** $P < .01$]. (RH = right hand; LH = left hand).

[4] It is possible that effects of hands, clefs or interactions between them are found but we lack the statistical power to detect them.

there are a relatively large number of response options (N = 5) and the response options are remapped from block to block. The point that we wish to emphasize is that the effect of synaesthetic incongruency is reliably found even though it is variable in magnitude.

The results of this experiment need to be contrasted with the previous ones. In the present experiment the color was completely irrelevant to the task (which required a simple sensory-motor mapping between position on the stave and keyboard), whereas in the previous experiments color was the dimension that was responded to. When stated in this way, a Stroop effect in the present task, but not the previous ones, is striking. We suggest that the difference can be accounted for because the present experiment requires processing of the identity and meaning of the note but the previous experiments did not (or the participants could develop strategies to minimize it).

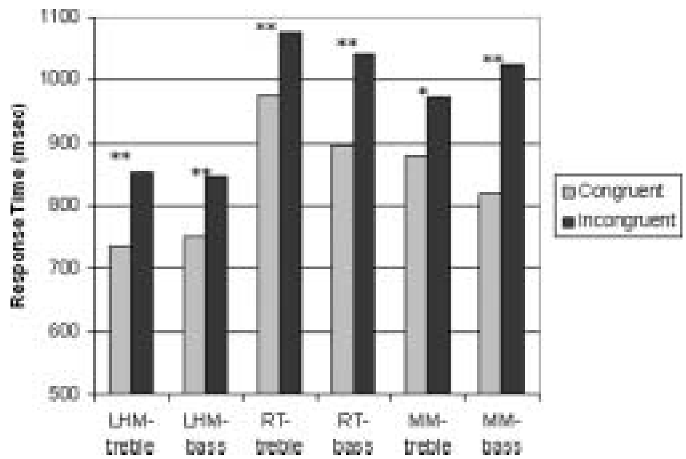

Fig. 4. Stroop interference is found when synaesthetes have to name their synaesthetic colour [* P < .05, ** P < .01].

Experiment 4: Stroop Interference for Naming Synaesthetic Colors

As already suggested, in Experiments 1 and 2 it may be possible to identify the color of the notes without necessarily identifying the note itself. However, if we change the instructions and ask the synaesthete to name their synaesthetic color, ignoring the color on the computer screen, this requires them to process the identity of the note more deeply. This 'reverse Stroop' method has been applied in a number of other studies of synaesthesia (e.g., Dixon *et al*., 2004; Ward, 2004).

Method

The same stimuli and procedure were used as in Experiment 1 for the treble clef and bass clef blocks. The only difference was in terms of the instructions. The synaesthetes were required to name the color of their synaesthetic experiences whilst ignoring the color of the note displayed on the computer.

Results and Discussion

The results are summarized in Figure 4. A significant effect was found across all the synaesthetes and for all conditions tested. These results are remarkable given that the same stimuli were used as in Experiment 1 and the only difference is that participants must name the synaesthetic color and ignore the veridical color (rather than vice versa). We explain this difference by assuming that deriving the synaesthetic color for a note depends on recognizing the identity of that note, whereas naming the veridical color can be achieved without fully processing the identity of the note.

General Discussion

This study reports the first empirical investigation of synaesthesia involving color for musical notation. Our starting point was to use the synaesthetic Stroop effect in which naming of veridical colors is slowed when the synaesthetic color is incongruent (e.g., Mills *et al*., 1999; Mattingley *et al*., 2001). Whilst this result was found for graphemes, replicating many previous studies, it was not found for written musical notes (except for MM in Experiment 2). However, we were able to provide other lines of evidence to suggest that this form of synaesthesia is genuine by using two modifications of the Stroop task. Firstly, synaesthetes are slow at playing musical notes when they are printed in the synaesthetically incongruent color. Secondly, synaesthetes do show Stroop interference when they are required to name their synaesthetic color and ignore the veridical color. We conclude that this form of synaesthesia is most strongly elicited under conditions in which the identity of the note requires processing. This is the first ever demonstration of synaesthesia for this type of stimulus.

Our results add weight to the suggestion that synaesthesia can be induced from conceptual processing of a stimulus (e.g., Dixon *et al*., 2000; Dixon *et al*., 2006). In the case of musical notation, the physical shape of the note has no bearing on the induced color: mimims, crotchets, quavers and so on all have the same color in our three synaesthetes (and RT has the same colors for sharps and flats written in the key signature). Nor does the vertical position of the note itself determine the induced color: the same positions on the bass and treble clefs have different colors. Rather the identity of a written note is determined by the musical context in which it is played (e.g., the clef, the key, and the vertical position on the stave). A functional imaging study of learning to read and play music identified regions in both the superior parietal lobes and the fusiform gyrus (Stewart *et al*., 2003). These regions are likely to be associated with sensory-motor transformations and note identification respectively, and both processes are likely to be important for eliciting this type of synaesthesia.

Our results also have implications for understanding how synaesthesia may develop and evolve over time. It is remarkable that in all three of the cases there is a close correspondence between the color of musical notes and the color of the graphemes (A to G) that are arbitrarily used to denote them. It is generally assumed that skilled musical reading does not require transcoding of the written note to a verbal label and thence to a manual response, and there is no reason to believe that our synaesthetes verbally transcode. All three play music at an advanced level in which several notes need to be processed simultaneously and bimanually. It is encouraging that the synaesthete that demonstrates the most interference is also the most musically accomplished (MM is a professional opera singer). If a more naïve verbal recoding strategy were used, we would expect interference to be strongest in the least skilled of our synaesthetes. Studies of musicians who have sustained brain damage have shown that it is possible to play musical notes in the face of aphasic difficulties in naming musical notes and written letters (Bevan *et al*., 2003), and that it is possible to lose the ability to play, read or write musical notes without losing the ability to read and write letters (Cappalletti *et al*., 2000). This suggests that music reading is independent of verbal abilities in musically skilled people. Our suggestion is that the color of musical notes derived from letters in the early phases of musical literacy and that, over time, musical notes may come to elicit such colors independently of any other code. This resembles studies of bilingual synaesthetes in which colors have been incorporated into the alphabet of a second script (e.g. Mills *et al*., 2002). Presumably the colors associated with processing the second language in fluent readers does not arise from online translating back to their first language but has an independent existence for that script. Novice second language learners are believed to initially recode from their second language (L2) to first language (L1) and thence to semantics (L2→L1→semantics) but as they become more fluent, each language gains independent access to semantics (L2→semantics, L1→semantics; e.g., Potter *et al*., 1984). It is conceivable that a similar process occurs in learning to read music (novice: music notation→letter name→playing; expert: music notation→playing).

Thus, one general conclusion that we would wish to draw from the present study is that synaesthetic associations can be shaped by experience and are not fixed from a very young age. This is not to deny that there is a hereditary component to synaesthesia (Ward and Simner, 2005) or that *some* forms of synaesthesia may be present in infants (Maurer, 1997). An understanding of the types of synaesthesia found in adults is likely to require an understanding of both innate and environmental factors. We do not wish to conclude that all cases of colored musical notation will follow the pattern that is described here. We wish to stress the role of experience, and experience will differ from case to case. Synaesthesia may be modulated by cultural quirks (e.g., how we label musical notes, and whether we label them at all) and differences in tuition and learning style.

Finally, while our study shows that synaesthetic associations may migrate from one visual-symbolic representation to another, in other individuals synaesthetic associations may migrate cross-modally. Our three synaesthetes report that 'A' notes heard played on the piano have completely different colors from the letter 'A' and the written musical note 'A' (see Table 2 again). However, for many synaesthetes already reported in the literature there is a correspondence between the color of graphemes and the color of *heard* pitches that are arbitrarily denoted by that name (e.g. Sachs, 1812; Langfeld, 1914; Riggs and Karwoski, 1934; Rogers, 1987; Carroll and Greenberg, 1961; Haack and Radocy, 1981). Thus, if the grapheme 'A' is red then, for these individuals, so will be the heard notes of 220Hz, 440Hz, 880Hz (etc.) that are arbitrarily denoted as 'A' on the English musical scale. This was also noted in the first documented study of synaesthesia nearly 200 year ago: "The tones of music follow the letters with which they are labelled" (Sachs, 1812)[5]. We suggest that, in these cases, the nature of cross-modal sound-color associations has been influenced by grapheme-color associations. In sum, the type of mechanism that we have postulated for musical notation-color synaesthesia may well generalize to many other types of synaesthesia. It is hoped that a fuller understanding of this mechanism may shed light on the issue of how perceptual processes come to be (at least in most individuals) largely independent of abstract or symbolic systems.

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[5] Taken from a German translation (page 101, Schlegel, 1824) of the original manuscript published in Latin.

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