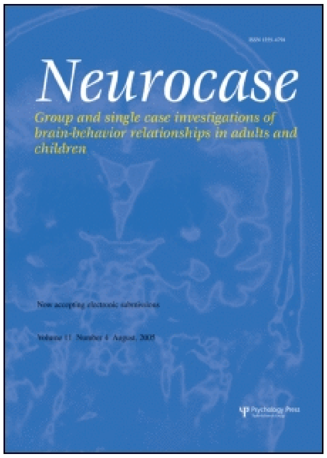

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Synaesthesia for Finger Counting and Dice Patterns: A Case of Higher Synaesthesia?

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Synaesthesia is often triggered by numbers, although it is conceivable that different aspects of numerical representation are responsible for different variants of synaesthesia. For individuals with "higher synaesthesia" it is assumed that number meaning (or numerosity) is responsible for the elicitation of synaesthetic experiences. This study documents a case study of a synaesthete, TD, who broadly fits this profile. TD reports that the same colours are elicited from physically different representations of number (digits, dice patterns and finger counting) provided that they share the same numerosity. The authenticity of his synaesthesia is established using Stroop-like priming and interference paradigms. Not only does synaesthetic colour interfere with veridical colour judgements, but also veridical colours can interfere with numerosity judgments. This suggests a close bi-directional coupling between numerosity and colour. Together, these findings constrain theories concerning the neural basis of synaesthesia.

Introduction

Perhaps the most commonly studied type of synaesthesia is that in which alphanumeric symbols trigger sensations of colour. We refer to this, here, as grapheme-colour synaesthesia. One debate in the literature concerns whether it is the physical form of the grapheme or the conceptual processing of the grapheme that is responsible for eliciting the colour (e.g., Dixon, Smilek, Cudahy, & Merikle, 2000; Dixon, Smilek, Duffy, & Merikle, 2006). These two different interpretations could lead to very different models of synaesthesia in terms of its neural basis. It has recently been suggested that different types of synaesthesia may exist in different individuals, giving rise to individual differences within the grapheme-colour variety of synaesthesia (Hubbard, Arman, Ramachandran, & Boynton, 2005). Ramachandran and Hubbard (2001) have termed those synaesthetes in whom the conceptual properties of a grapheme trigger colours as "higher synaesthetes" and those in whom the physical properties of a grapheme trigger colours as "lower synaesthetes." It is also conceivable that these two hypothetical types of synaesthesia represent end points of a continuum with most synaesthetes lying between (Hubbard et al., 2005; Ward, Salih, Li, & Sagiv, in press). One of the characteristics attributed to higher synaesthetes is that the same colour may be found for different physical representations of the same stimulus. This can be most conveniently illustrated with numerical stimuli given that these exist in multiple codes such as digits (e.g., 4), number names (FOUR), roman numerals (IV), dice patterns, finger counting, and so on. Ramachandran and Hubbard note that some synaesthetes report Roman numerals to have the same colour as digits (e.g., IV has the same colour as 4). However, no systematic investigation of such a case has been carried out. The present study will document a case of higher synaesthesia.

The conceptual representation of number is often referred to as numerosity (Butterworth, 1999). Numerosity refers to the integer size of the collection, irrespective of what is being counted. Several recent studies have suggested a close link between numerosity and the elicitation of colour in synaesthesia. Moreover, these studies suggest that the link between colour and numerosity is bi-directional. Cohen Kadosh et al. (2005) presented synaesthetes with pairs of digits (e.g., 4 vs. 6) and asked which was numerically larger. The digits also happened to be coloured either consistently with their synaesthesia (i.e., "4" was 4-coloured and 6 was 6-coloured), or with colours that exaggerate numerical distance (i.e., 4 was 2-coloured and 6 was 9-coloured). The synaesthetes were faster in the latter condition relative to the former suggesting that the numerosity implied by the colours interacted with the true numerosity of the digits.[1] The

[1]In fact, this is the only example in the synaesthesia literature (of which we aware) in which synaesthetically incongruent colours lead to faster performance than synaesthetically congruent colours.

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effect is likely to be due to number meaning (rather than the physical representation of a digit) because similar results were obtained when the length of two coloured lines was compared (Cohen Kadosh & Henik, 2006b).

The synaesthete reported here, TD, is remarkable in at least one other respect. Namely, that the colours are subjectively projected not only on to the surface of the page when reading text, but also on to the surface of a die, and on to the surface of his fingers and hand when counting. This particular variety of synaesthesia has been termed "projector synaesthesia" although it has only previously been documented in the context of viewing text (Dixon, Smilek, & Merikle, 2004). Projector synaesthetes may be contrasted with the more common variety of "associator synaesthetes" in whom the colours are perceived as being located internally or in their "mind's eye" rather than in the same spatial location as the grapheme that induced it (Dixon et al., 2004). Whereas the projector/associator distinction categorises synaesthetes on the basis of the experienced phenomenology, the higher/lower distinction categorises synaesthetes on the basis of the level of induction of the synaesthesia (perceptual versus conceptual). A number of recent papers have claimed that these two distinctions may collapse on to one another such that projector synaesthetes have a perceptual level of induction (i.e., projector = lower) and associator synaesthetes have a conceptual level of induction (i.e., associator = higher) (Dixon & Smilek, 2005; Hubbard et al., 2005). Taken at face value, the existence of a synaesthete such as TD is problematic for this account because he is a projector and he appears to have higher synaesthesia. An alternative account of varieties of grapheme-colour synaesthesia will be presented in the discussion.

The experimental investigation below provides evidence that corroborates TD's description of his synaesthesia. Given that we cannot have access to TD's first-person experiences, researchers have developed other measures to establish the authenticity of synaesthesia. In the studies below, we take advantage of the fact that synaesthetic experiences are reported to be automatic, reliable and inevitable. In particular, synaesthetes have been shown to have difficulty in ignoring their synaesthetic colours when required to name the physical colour of a stimulus (e.g., Mattingley, Rich, & Bradshaw, 2001; Mills, Boteler, & Oliver, 1999), a situation that closely resembles the common Stroop task.

Case description

TD is a 37-year-old, right-handed male with English as his native language. He reports synaesthetic colour sensations in response to letters, digits, words, pain, music, noise, smell, and taste. In addition, he reports experiencing sequential concepts (days, months, numbers, alphabet) in spatial forms (Galton, 1880; Sagiv, Simner, Collins, Butterworth, & Ward, 2006). To date, we have only tested his synaesthesia for verbal stimuli (presented both from speech and reading). His internal consistency for letters and single digits ($N = 36$) was 100% after a 2-month retest.

When reading, TD reports that the synaesthetic colours are located in external space, on top of the text itself. Dixon et al. (2004) have termed this type of synaesthete a "projector." TD performs like other projectors on objective measures (Ward et al., in press). In particular, he is faster at naming his synaesthetic photisms for digits relative to naming the veridical colour in which they are displayed (by 154 ms, reported in Ward et al., in press). Both Dixon et al. (2004) and our own group (Ward et al., in press) have found this to be reliable discriminator of projector synaesthetes, with associator synaesthetes showing the reverse profile.

TD also reports projected synaesthetic colour experiences when viewing dice patterns and when finger counting on his own hand. What is of particular interest is that the colours he reports for fingers and dice are the same as those reported when viewing written digits (1, 2, 3, etc.). For example, the number 5 is a cardboard box-like brown colour both when he sees or hears the digit "5," when he looks at the five dots on a dice, and when he counts or observes the five fingers on his hand. TD reports finger counting in a particular way, commencing with the left hand and with his thumb outstretched to the left. As fingers become uncurled, colours become projected on to that part of the surface of the hand. The whole hand is not coloured, only the outstretched fingers are coloured together with the exposed part of the palm below them (i.e., the curled portion of the hand does not get coloured). As a new finger is uncurled the whole stimulus flips in colour. TD's finger counting is illustrated in Figure 1 (synaesthetic colours not shown).

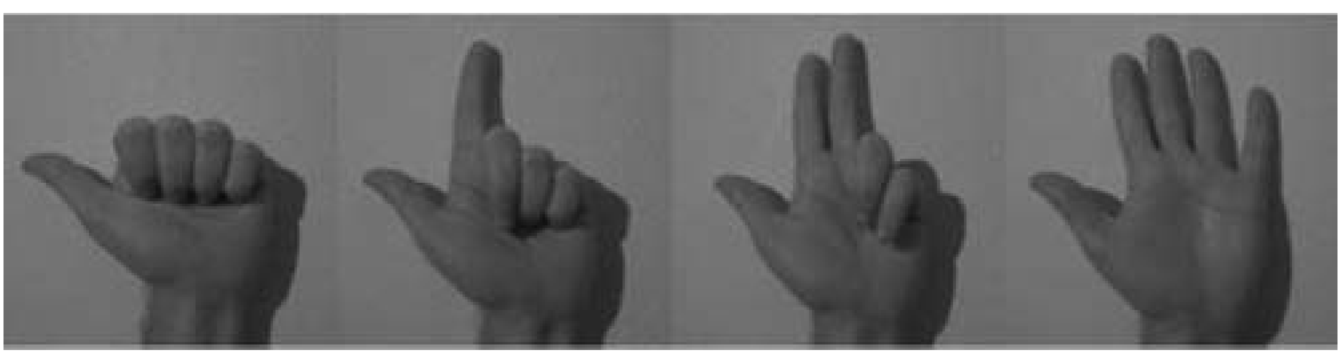

Fig. 1. TD's finger counting for numbers 1, 2, 3 and 5. (The number 4 was not used in the study. To count 4, TD uses his other hand in order to hold the fifth finger down.)

Experimental investigation

Experiment 1: Priming of colour naming with hand configurations

The aim of the first experiment was to find an objective measure that is consistent with TD's claims of experiencing colours from hand configurations used in finger counting. To do this we used a priming/interference paradigm in which a task-irrelevant prime is presented (a hand configuration) followed by a coloured stimulus to which TD must respond. The synaesthetic colour induced by the hand could either be congruently or incongruently coloured with the subsequent probe, but note that the hand itself was presented in its natural flesh colour (i.e., it was neutral with regards to synaesthesia). This resembles previous studies in the synaesthesia literature in which a physically achromatic grapheme (that induces a synaesthetic colour) is followed by a coloured stimulus that requires a response (Mattingley et al., 2001). Our prediction was that TD would be significantly faster on congruent relative to incongruent trials.

As already noted, TD reports using a particular style of finger counting and he claims that his synaesthesia is dependent on this. In order to test this claim, we presented him with visuo-spatial hand configurations that were either consistent with his counting style (e.g., counting 1 to 5 on the left hand) or inconsistent with it (e.g., counting 1 to 5 on the right hand). If TD's synaesthesia is linked to this particular counting style then we would expect the amount of colour interference to be greatest with the normal counting configuration (i.e., an interaction between colour congruency and familiarity of the hand configuration). If, however, TD's synaesthesia depends on numerosity alone (i.e., the number of fingers displayed in any configuration) then no interaction with congruency would be expected.

Method

The stimuli consisted of TD's left hand positions for counting the numbers 1, 2, 3 and 5 (see Figure 1). Four was omitted because TD uses his other hand to hold down the little finger when counting this number. Given that TD only ever uses his left hand for counting these numbers, it was interesting for us to compare his performance for left hand stimuli relative to different visual configurations. In one condition (handedness manipulation), the left hand stimuli were contrasted with the same configuration on the right hand (obtained by mirror reversing the set of left hand images). In another condition (visual field manipulation), a left hand was presented on either the left or right of central fixation. In the third condition (perspective manipulation), only the left hand was used again and was always presented in the centre but was either presented the right way up (wrist at the bottom) or upside-down (wrist at the top). The first two conditions were presented in a single session (along with Experiment 3 below) and the third condition was presented in a separate session some 8 months later (along with Experiment 2 below).

A $3 \times 2 \times 2$ design was used contrasting the visual configuration of the hands (three levels, described above), whether the visual configuration was consistent with TD's reporting style or not (two levels, consistent and inconsistent), and the colour congruency between the prime and probe (two levels, congruent and incongruent).

In each condition, there were 144 trials. There were equal numbers of each trial type and of each hand configuration. The trials were presented over three blocks with short breaks in between. The procedure on each trial was as follows. A fixation cross, white on black, was displayed centrally for 800 ms. Immediately afterwards the hand was displayed on the screen for 400 ms, which TD was instructed to ignore. The image was presented surrounded by a black background. Following this, a synaesthetically neutral stimulus (###) was displayed centrally in either a colour that was congruent or incongruent with the synaesthetic colour induced by the numerosity of the previous hand configuration. The stimulus remained on the screen until the participant responded by naming the colour as quickly as possible into a microphone.

Results

TD made no errors. Response times greater than 3 standard deviations from the mean were excluded. The results are summarised in Figure 2. A $3 \times 2 \times 2$ ANOVA revealed a significant main effect of colour congruency [$F(1, 420) = 211.80$, $p < .001$] showing that TD was faster to name veridical colours if they were preceded by a prime of the same synaesthetic colour. This provides evidence for the authenticity of his synaesthesia. There was a significant main effect of the different visual configurations of the hand [$F(2, 420) = 29.23$, $p < .001$] and this interacted with colour congruency [$F(2, 420) = 3.98$, $p < .05$]. This suggests that some visual configurations elicit synaesthesia more effectively than others. However, there was no main effect of whether the visual configurations were consistent with TD's counting style (i.e., left hand relative "right" hand, left hand in right space, or upside-down left hand) and this did not interact with anything else (all p values >.10).

In summary, Experiment 1 provides evidence for the authenticity of TD's synaesthesia induced from viewing hand configurations. He was unable to ignore the synaesthetic colour of the task-irrelevant prime. The findings reported here suggest that TD's synaesthesia may be related to the number of fingers displayed (i.e., the numerosity) rather than the physical form of the stimulus, although the latter may have a modulating influence on the size of the Stroop interference.

Experiment 2: Interference of number naming with hand configurations

In this experiment, TD was given two different sets of task instructions: to name the colour ignoring the numerosity (as in Experiment 1) and to name the numerosity ignoring the colour (to assess bi-directionality). Other studies have shown that colours can automatically activate numerical representations

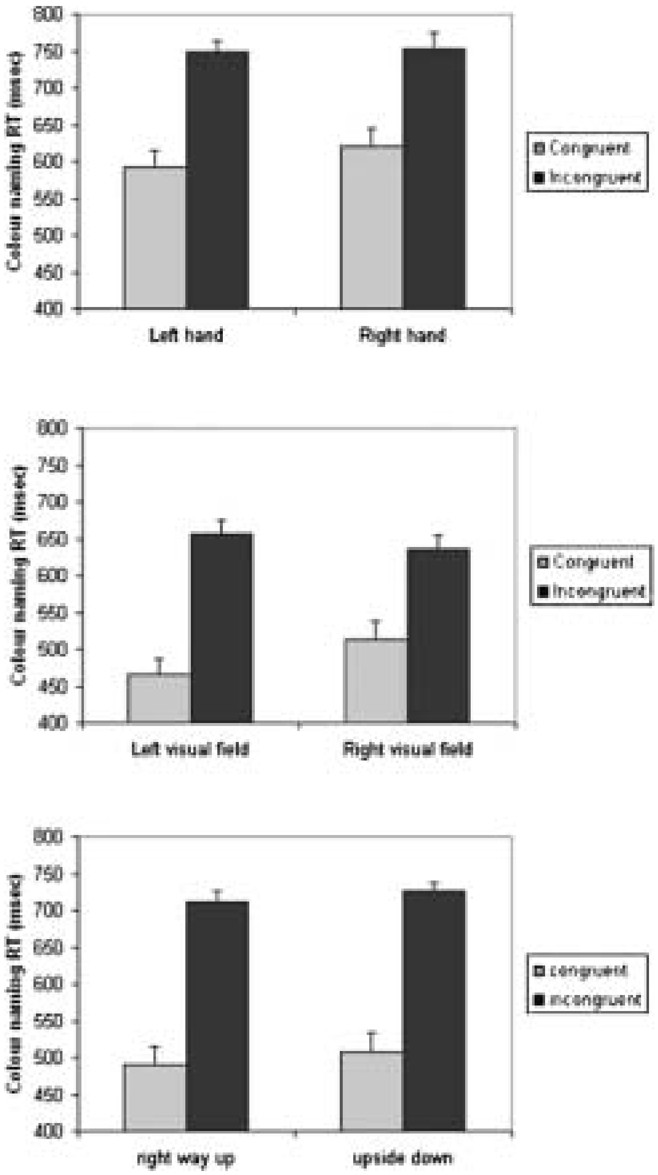

Fig. 2. Voice onset times (ms) to name the colour of a probe stimulus (###) following brief presentation of prime stimulus that induces synaesthesia (a hand configuration). The hands were presented in three conditions: a left or right hand in the centre of the screen (top graph), a left hand in either the left or right visual field (middle graph), a left hand presented the right way up or upside down (bottom graph). Error bars show 1 S.E.M.

as well as vice versa. It is possible that this is always true of higher synaesthesia, although further research is needed. However, we note that this bi-directional effect is likely to be implicit given that colours do not evoke synaesthesia per se (TD does not report seeing digits when looking at colours).

Method

This experiment was based on a $2 \times 2 \times 2$ design contrasting colour congruency between veridical and synaesthetic colour (congruent vs. incongruent) the visual configuration of the hands (left/right visual field vs. left/right hand presented centrally) and consistency with TD's counting style (left being consistent and right being inconsistent). The stimuli were different to those used in Experiment 1 such that the exposed part of the hand was coloured using Adobe Photoshop along the lines of TD's phenomenological description. Thus, in this experiment, the stimulus colour and finger numerosity were aspects of the same stimulus rather than presented as a separate prime and probe. In order to assess whether this affects performance we attempted to replicate the results of Experiment 1 by asking TD to name the colour of the hand, ignoring his synaesthetic colour. However, the main purpose of the experiment was to determine whether the stimulus colour affects numerosity judgments. In order to do this, the instructions given to TD were changed with all other aspects of the experiment held constant. TD was asked to state the number of fingers shown (1, 2, 3 or 5) ignoring, if possible, the numerosity implied by the stimulus colour.

Each block consisted of 144 trials. There were four blocks in total which were presented in the following order: naming colour of left/right hands; naming colour of hands in left/right space; naming number of fingers of left/right hands; naming number of fingers of hand in left/right space. The procedure for each trial was as follows. A fixation cross was presented centrally for 800 ms. The cross was white on a black background. After this, the partly coloured hand was displayed on the screen and remained on the screen until TD made a response. The stimulus was displayed against a black background. TD made a response by stating the colour name or the number of fingers as quickly and accurately as possible into a microphone attached to a voice key. The next trial began immediately after the response. The stimuli were presented in a random order.

Results

TD made no errors. Response times greater than 3 standard deviations from the mean were excluded. Figure 3 shows TD's response times for naming the number of fingers. TD was significantly faster at naming the number of fingers when the colour of the stimuli was congruent with the numerosity [main effect, $F(1, 276) = 48.52$, $p < .001$]. This suggests that, in some synaesthetes such as TD, colours can automatically activate numerical representations giving rise to interference when the number implied by the colour differs from the actual numerosity of the stimulus. This result is similar to that previously reported for Arabic digits (Cohen Kadosh & Henik, 2006a; Cohen Kadosh et al., 2005) and line length judgments (Cohen Kadosh & Henik, 2006b). There was a non-significant trend for TD to be faster at naming the numerosity when the configuration was consistent with his counting style [main effect, $F(1, 276) = 3.56$, $p = .062$], but no main effect of visual configuration (visual field vs. handedness) and no interactions (all p values >.10).

When TD was asked to name the colour of the stimulus, his response times were significantly affected by the synaesthetic

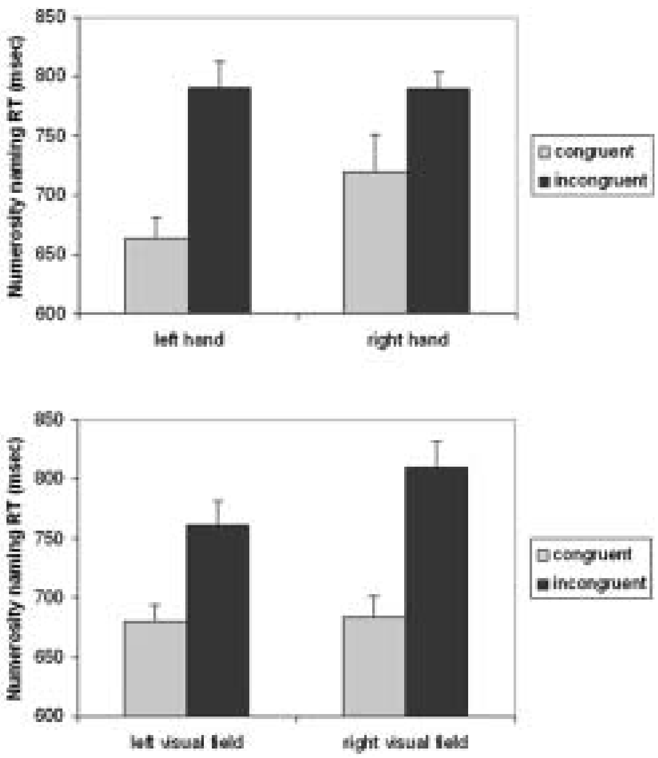

Fig. 3. Voice onset times (ms) to name the number of fingers on a hand. The hands were either coloured appropriately to the number of fingers (congruent condition) or implied a different numerosity (incongruent condition). Top graph: left/right hand; bottom graph: left/right visual field. Error bars show 1 S.E.M.

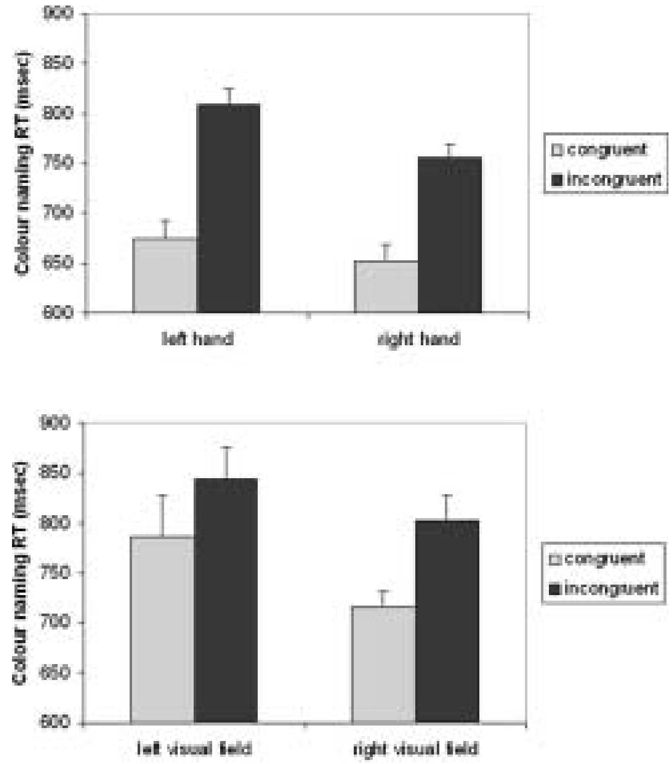

Fig. 4. Voice onset times (ms) to name the colour of the hand, ignoring the synaesthetic colour. The hands were either congruent or incongruent with respect to the induced synaesthetic colour. Top graph: left/right hand; bottom graph: left/right visual field. Error bars show 1 S.E.M.

congruency [main effect, $F(1, 275) = 31.67$, $p < .001$], by the visual configuration [main effect, $F(1, 275) = 14.30$, $p < .001$] and whether the visual configuration was consistent with his counting style [main effect, $F(1, 275) = 7.95$, $p < .005$]. However, there were no interactions between any of these (all p values >.10). These results are summarised in Figure 4. These results are similar to Experiment 1 (although note that the visual configuration manipulation of rotating the hand was not included in Experiment 2).

In summary, Experiment 2 has shown that the colour of a visually presented hand may activate numerical representations giving rise to Stroop-like interference when the number of fingers is stated. The effect is found when the hand is presented in different orientations and positions. This suggests that there is a close bi-directional coupling between number and colour that is relatively invariant to the stimulus format.

Experiment 3: Stroop interference with coloured dot arrays

The other type of numerical stimulus that TD reports colours for is dice patterns. In this experiment, we investigate the authenticity of this claim using Stroop interference from synaesthetic colours when attempting to name the veridical colour of the display. As before, in order to assess whether synaesthesia is tied to the familiarity of the visual display rather than the numerosity, the dot patterns consisted either of familiar dice patterns or unfamiliar random arrays of the same numerosity.

Method

The stimuli formed part of a 2 × 2 experimental design in which the colour of the dots was contrasted (either congruent or incongruent with synaesthetic colour) as was the arrangement of the dots (either a dice configuration or a random configuration). The incongruent trials were created using the same colours as in the congruent trials but reassigned to a different array size. The random dot arrangements covered the same spatial extent on the computer screen as the dice patterns (both within a 12 × 12-cm area). There were 100 trials in each of two blocks, with equal numbers of trials from each of the four conditions. The size of the arrays varied from 2 to 6 with equal proportions of each in each condition.

The procedure in each trial was as follows. A fixation cross was displayed centrally for 1500 ms (white-on-black). Following this, the coloured dot array appeared on the screen against a black background and remained visible until a response was made. The participant was required to name the veridical colour as quickly as possible into a microphone (i.e., ignoring synaesthetic colour). Following this, the next trial began immediately.

Results

The results are summarised in Figure 5 excluding a small number of trials (0.5%) in which errors were made or the microphone was not triggered appropriately. A 2 × 2 ANOVA revealed a significant interaction between congruency and the configuration of the dots [$F(1, 192) = 8.23$, $p < .005$]. The main effect of congruency was borderline significant [$F(1, 192) = 3.75$, $p = .054$] but there was no main effect of configuration [dice vs. random; $F(1, 192) = 0.67$, *ns*]. *Post hoc t*-tests revealed that the interaction can be explained in terms of a significant effect of congruency on the dice configurations [$t(95) = 3.20$, $p < .005$] but no such effect on the random configurations [$t(97) = 0.71$, *ns*]. As such, the induction of synaesthetic colour appears to be specific to the familiarity of the stimulus rather than number concepts per se.

It is well established that the number of items in an array is automatically computed up to array sizes of 3 or 4 (a process called subitizing, Mandler & Shebo, 1982), whereas for larger arrays a slower serial process is needed to compute the size of the array (i.e., counting). If the induction of synaesthetic colour was due to number meaning itself then one might expect a difference between small arrays (two to three items) relative to larger arrays (five to six items). The lower part of figure 5 displays the data for small versus large arrays. As before, the largest effect is related to whether or not the arrays are familiar dice patterns and not due to numerosity per se. For example, the difference between incongruent and congruent trials is 71 ms for dice patterns of two to three dots but only 16 ms for random configurations even though both are within subitizing range. Planned comparisons reveal that significant congruency effects were found for the larger dice patterns [$t(36) = 2.73$, $p < .05$], but not small dice patterns [$t(37) = 1.46$, *ns*], or the small random patterns [$t(38) = 0.52$, *ns*], or the larger random patterns [$t(37) = 1.03$, *ns*].

In summary, this experiment establishes for the first time that dice patterns can act as an inducer of synaesthesia. In contrast to the experiments with finger counting, there was evidence to suggest that the effect was mediated by the visual configuration of the dots rather than the number of dots per se. However, the relationship between colour and numerosity is still likely to have contributed to the pattern observed. This is because the synaesthetic colours of the dice pattern are the same as those for other numerical codes (numbers and fingers). The numerosity presumably played a role in the establishment of the initial colour correspondences during TD's developmental history, even though the visual configuration of the dots appears to be the strongest influence on TD's synaesthesia at the present time.

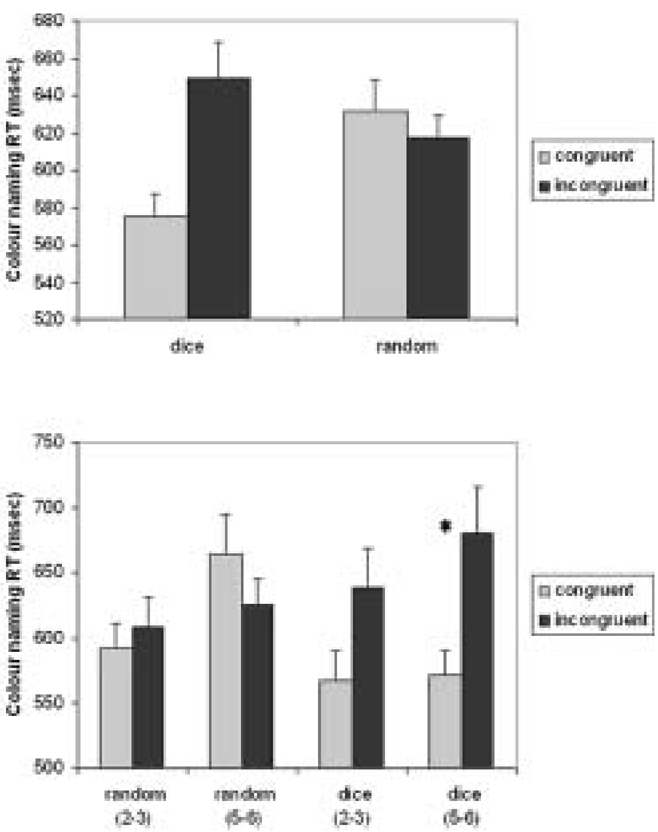

Fig. 5. Voice onset times (ms) to name the colour of an array of dots. The dots were either arranged into a familiar dice configuration or were randomly arranged. The colour of the dots was either consistent or inconsistent with the synaesthetic colour associated with that numerosity. Error bars show 1 S.E.M.

General discussion

This study provides the first empirical demonstration that number–colour synaesthesia can be induced by numerical symbols such as dice patterns and finger counting although these patterns have been anecdotally noted before (e.g., Ramachandran & Hubbard, 2001; Ward et al., in press). It provides convincing evidence for the role of conceptual representations in the induction of synaesthesia. During development, these numerosity–colour associations may become linked to culturally acquired symbols such as written digits and conventional dice patterns. Other types of synaesthesia support the notion that synaesthetic colour associations may migrate from one system of representation to another on the basis of shared conceptual or perceptual properties. Thus, for some synaesthetes the colours of written musical notes take on the colours of the names that arbitrarily denote them (Ward, Tsakanikos, & Bray, 2006) or the colours of alphabetic systems from a second language (e.g., Greek, Cyrillic) take on the colours of earlier acquired alphabets (e.g., Mills et al., 2002; Witthoft & Winawer, 2006).

Further evidence for a direct link between colour and numerosity comes from the fact that the physical colour of a stimulus can bias numerosity judgments. TD's ability to state the number of fingers displayed on a hand was affected by whether the colour of the hand happened to be congruent or incongruent with the response. This resembles a previous demonstration of this effect with Arabic digits (Cohen Kadosh & Henik, 2006a). It is likely that there is reciprocal activation between numerosity and colour even in those instances in which synaesthesia itself is unidirectional (i.e., numbers trigger conscious experiences of colour, but colours do not trigger conscious experiences of number).

The results presented here are consistent with recent behavioural priming studies (e.g., Koechlen, Naccache, Block, & Dehaene, 1999; Reynvoet & Brysbaert, 2004) and neurophysiological investigations (e.g., Piazza, Pinel, Le Bihan, & Dehaene, 2007; Venkatraman, Ansari, & Chee, 2005) that show priming effects between different notations representing the same numerosity. These studies have not always contrasted the familiarity of the stimulus (e.g., familiar counting patterns, dice patterns) with the numerosity although both may be important, as familiar objects may have a different status to a collection of parts. In this study, the effect of stimulus familiarity was more apparent in the dice patterns than in the finger counting. However, the manipulations are not directly comparable since spatial aspects of the hands were manipulated (by reflecting, rotating, translating) rather than the configuration per se (e.g., creating a numerosity of 3 by folding down the middle and ring finger instead of folding down the ring and little finger). For the dice patterns, the dots were re-arranged rather than the whole configuration being rotated (which tends to preserve the object as a whole). However, stimulus familiarity cannot explain all the effects reported here. The fact that different notational formats have the same colour must be related to numerosity itself.

The evidence presented from TD may be helpful for adjudicating between different theoretical models of synaesthesia. Ramachandran and Hubbard (2001) provide a number of criteria which they claim may be indicative of “higher synaesthesia” of which colour for different numerical symbols is just one. Another feature that they attribute to higher synaesthesia is the tendency to visualise sequential concepts as spatial forms (e.g., months of the year arranged in a circle in peri-personal space). Indeed, TD also reports this. However, Ward et al. (in press) have shown that in other synaesthetes these two features do not always co-occur. Thus it appears that a synaesthete can be higher in one respect but not another. We speculate that this may be related to the fact that the conceptual representation of number has two elements; namely ordinality and cardinality. Numbers can be ranked according to their position in a sequence (ordinality) or with respect to their magnitude/numerosity (cardinality). The ordinality of numbers may be associated with visuospatial properties such as number forms, given that they tend to co-occur with spatial forms for time and the alphabet (Sagiv et al., 2006). These concepts also possess ordinality but not cardinality. In contrast, the effects of colour on numerosity judgments could be construed as a relationship between cardinal aspects of number meaning and colour, as can the fact that different numerical symbols possess the same colour (an effect of ordinality on colour might manifest itself as “January” having the same colour as 1, “February” having the same colour as 2, etc.). One final claim made about higher synaesthetes is that they may also be associators in that they experience their colours internally in their “minds eye” (Dixon & Smilek, 2005). This suggestion is based on the assumption that a semantic representation of number may be more likely to make contact with a more conceptual (and less perceptual) representation of colour (Ramachandran & Hubbard, 2001). The evidence from TD is problematic for this account because TD says he is a projector (not an associator); TD behaves like a projector rather than an associator on a number of objective tests (Ward et al., in press); but yet TD shows the other defining characteristics of a higher synaesthete.

Other theories can account for some aspects of TD’s synaesthesia. For example, the notion of re-entrant processing (Dixon et al., 2004) between graphemes and colours can account for bi-directionality. However, the only model that we are aware of that can account for the whole pattern is the one recently put forward by Ward et al. (in press). In this model, the mechanisms that give rise to the projector–associator distinction are independent from those that give rise to higher-lower characteristics. Thus, it is quite feasible to be a projector with higher synaesthesia. The projector–associator distinction is assumed to reflect the different spatial reference frame in which colours and objects are bound together (i.e., internal, external, body-centred, etc.), whereas the higher-lower distinction is assumed to reflect the degree of conceptual involvement of the inducing stimulus. In the non-synaesthetic brain, information from different senses and the motor system is initially represented separately based on the sensory inputs (e.g., retinocentric, somatotopic) but these are combined into common spatial reference frames that code for different types of sensori-motor information (Andersen, Snyder, Bradlet, & Xing, 1997). Our model explains TD’s profile by assuming that colours are bound to stimuli in a reference frame that codes the location of external objects independent of viewpoint (a projector) and that the main level of synaesthetic induction is numerosity (a higher synaesthete). The model of Ward et al. (in press) also makes the prediction that the projector/associator distinction should not be limited to grapheme-colour but may be a general feature of synaesthetic perception that has parallels to non-synaesthetic perception and imagery. This study provides the first evidence to suggest that synaesthetic colours can be projected on to stimuli other than graphemes. The binding of different stimulus attributes to different spatial frames of reference appears to be a ubiquitous feature of normal perception and imagery. We suggest that the same mechanisms apply to synaesthetic perception too. As such, synaesthesia may prove to be a model system for understanding how different attributes of a stimulus processed in different neural resources (e.g., objects and colour) can give to a unified conscious percept.

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