

IS DIGIT-COLOR SYNAESTHESIA STRICTLY UNIDIRECTIONAL? PRELIMINARY EVIDENCE FOR AN IMPLICITLY COLORED NUMBER SPACE IN THREE SYNAESTHETES

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SUMMARY

Background. *The unidirectionality of associations constitutes an undisputed law of synaesthesia. In digit-color synaesthesia a digit elicits a concurrent color percept, but if the particular color is presented, it is usually devoid of numerical properties. Based on scattered case reports of synaesthetes whose phenomenal experience runs counter to the law of unidirectionality, we investigated implicit numerical encoding of colors in three digit-color synaesthetes.*

Material and methods. *Those colors regularly elicited by numerals were presented in the center of a computer screen in a spatial stimulus-response paradigm with bimanual responses.*

Results. *Left hand reaction times (RTs) were faster to colors representing small numbers, and right hand RTs were faster to colors representing large numbers. This SNARC effect (Dehaene, 1992) for purely chromatic information was absent for non-synaesthetic matched control subjects, who had previously learned the synaesthetes' digit-color associations.*

Conclusions. *This finding presents evidence for an at least implicit coactivation of number magnitude by color stimulation in synaesthetes, and thus questions the universality of the unidirectionality principle.*

INTRODUCTION

Synaesthesia is the phenomenal experience of a bimodal percept after stimulus presentation in only one modality. Currently heightened neuroscientific interest in the crossmodal integration of sensory information has generated a host of experimental studies with participants who experience synaesthesia in their daily life ("synaesthetes"). Neuroimaging work in subjects who synaesthetically associated colors to spoken words has shown synaesthesia-related activations in primary visual (Aleman et al., 2001) or in several extra-striate visual areas, either bilaterally (Paulesu et al., 1995) or lateralized to the left hemisphere (Nunn et al., 2002). One electrophysiological study in a relatively large group of synaesthetes (Schiltz et al., 1999) emphasized the role of prefrontal regions in the integration of multisensory information.

While these neuroimaging studies have begun to identify the functional neuroanatomy of the synaesthetic experience, cleverly designed behavioral experiments have uncovered some laws of the synaesthetic process. For instance, psychophysical experiments on perceptual grouping (e.g., Palmeri et al., 2002; Ramachandran & Hubbard, 2001a), visual search (e.g., Palmeri et al., 2002; Smilek et al., 2001), and visual-verbal interference (e.g., Mattingley et al., 2001; Mills et al., 1999; Odgaard et al., 1999) produced unequivocal evidence for the high automaticity of synaesthetic perceptions. Based on these and similar studies, one must conclude that synaesthesia involves a genuine perceptual experience and is not the product of mere mnemonic, or language-mediated associative processes.

One further law of synaesthesia concerns the unidirectionality between the two (or more) involved concurrent percepts. To illustrate this, a color-digit synaesthete may report "seeing" a pink color on watching (or merely imagining) the digit 7 in colorless print¹. However, glancing at a pink wall will as a rule *not* be accompanied by a simultaneous perception of an array of sevens, nor will the color pink elicit an abstract impression of "sevenness." In stark contrast to the law of automaticity, the law of synaesthetic unidirectionality has generated very little, if any, empirical research (see Mills et al., 1999, p. 187, and Rich and Mattingley, 2002, p. 48, for relevant post-hoc interpretations of their findings). In fact, as a consequence of the high agreement among synaesthetes regarding this issue, the law of unidirectional associations appears to have obtained the status of an axiom. It must be noted, however, that isolated incidents of bi-directionality have been reported in the literature (Baron-Cohen et al., 1996, p. 1077; Cytowic, 1998, p. 53), indicating that the law of unidirectionality may not be as universal as is commonly

¹ Note that this type of synaesthesia does not span across two major sensory modalities, but is nevertheless bimodal in that an achromatic stimulus triggers a color percept. Color-digit synaesthesia is among the most frequent types of synaesthesia, and has consequently been the subject of a large number of laboratory investigations (e.g., Dixon et al., 2000; Mattingley et al., 2001; Mills et al., 1999; Odgaard, et. al., 1999; Palmeri et al., 2002; Smilek et al., 2001).

assumed. Also, the possibility remains that, even if synaesthetic associations are experienced as unidirectional *on a conscious level*, "covert bi-directionality" may nevertheless be demonstrable on the level of implicit processing. The present study was planned to address this issue.

We tested three digit-color synaesthetes and twelve non-synaesthetes with a modified bimanual SNARC paradigm (Dehaene, 1992). The "SNARC effect" (*Spatial-Numerical Association of Response Codes*) refers to the observation that relatively small numbers are responded to faster by the left hand and relatively large numbers by the right. Similar stimulus-response compatibility effects are found for geometrical figures, provided their (arbitrary) association to specific left-sided or right-sided locations are *explicitly* learned (Bächtold et al., 2000). We investigated whether, specifically in synaesthetes, there was a left hand reaction time (RT) advantage for centrally presented colors associated with small numbers and a similar advantage of the right hand for colors associated with large numbers.

MATERIAL AND METHODS

Subjects

Synaesthete 1 (S1) is a right-handed (Chapman and Chapman, 1987) female social worker, 43 years of age. She experiences stable digit-color synaesthesia, predominantly to the numbers 1 to 11. Colors corresponding to the numerals 1 (black), 5 (green), 7 (red) and 11 (yellow) were selected for the present experiment because they could not be mistaken for representing other digits.

S2 is a right-handed female kindergarten teacher, 42 years of age, with especially stable digit-color associations for the number range 1 to 12. Colors corresponding to the numerals 2 (mandarin), 3 (red), 4 (green), 5 (light blue), 7 (turquoise), 8 (purple-red), 9 (indigo) and 11 (faint yellow) were selected as stimuli.

S3 is an ambidextrous man (biologist, age 52) who synaesthetically associates colors to a wide range of numbers (two-digit numbers being experienced as composites of different colors). The selected stimulus colors were pink (1), yellow (2), light blue (7) and dark blue (8).

All synaesthetes had a negative psychiatric (including drug abuse) and neurological history. In all three cases, the reported synaesthesia began in early childhood. Automaticity of individual digit-color associations was established prior to the experiment with a Stroop-type paradigm similar to that in Dixon et al. (2000) and was high in all three subjects.

Four control subjects were carefully matched to each of the synaesthetes according to gender, age, handedness and socio-economic background, and were tested with an identical procedure. Prior to the experiment, all control subjects learned the selected digit-color associations of their respective sy-

naesthete, and error-free paired-associate performance was assured before experimental testing.

All participants had been recruited by flyers and gave written informed consent to participate in the study as unpaid volunteers. Their vision was normal or corrected-to-normal. No subject had taken any medication during at least one week prior to testing.

Task and procedure

The experiment involved tachistoscopic presentations of color patches in the center of the visual field (stimulus extension approximately 4 x 4 degrees of visual angle; exposure time 30 ms; inter-trial interval 1000 ms). The individual stimulus colors had previously been selected by the synaesthetes from a PC color palette to match them as optimally as possible to their synaesthetic percept. In a first run (10 presentations of each color), subjects were trained to respond as quickly as possible to half of the colors with their left hand and to the remaining half with their right hand. In a second run of equal length, this color - hand assignment was reversed. Subjects were naive with respect to the variable of interest, i.e. magnitude of the color-associated numbers. Before each run, 10 practice trials were administered (not analyzed). The different colors were presented in a pseudorandom order. Testing lasted about 10 minutes for S1 and S3 and their individually matched control subjects (80 trials), and about 20 minutes for S2 and her control subjects (160 trials), as these subjects were presented with 8 instead of 4 unique colors.

RESULTS

In view of the small size of the experimental group no statistical treatment of the data was attempted, and they are presented here in purely descriptive form. Each group's mean RT to colors representing "small" numbers were contrasted to those to colors representing "large" numbers for each hand separately (see Figure 1). Only correct decisions were considered (error rates were smaller than 2% for both synaesthetes and controls). In the synaesthetes, "small number colors" were responded to faster with the left hand (M = 545 ms, SD = 48 ms) than with the right (M = 789 ms, SD = 481 ms). Conversely, the right hand responded faster to "large number colors" (M = 541 ms, SD = 101 ms) than did the left hand (M = 865 ms, SD = 614 ms). In the non-synaesthetes, no similar interaction pattern emerged (left-small: M = 573 ms, SD = 233 ms; left-large: M = 564 ms, SD = 181 ms; right-small: M = 579 ms, SD = 244 ms; right-large: 547 ms, SD = 218 ms). We noted that the reaction times of the synaesthetes were similar to those of the control subjects in the (implicitly) *compatible* assignment of response hand and color-associated number magnitude. The RT of the synaesthetes, however, were considerably longer exclusively in the *incompatible* assignment, i.e., the interference condition.

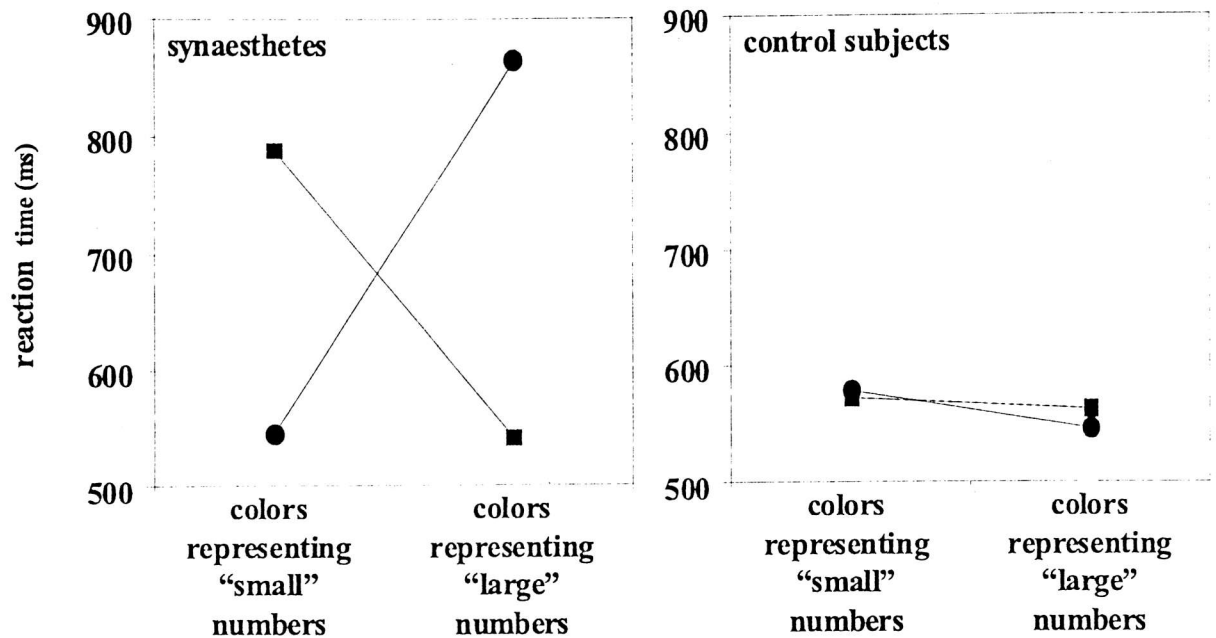


Fig. 1. Mean reaction times to centrally presented colors representing "small" and "large" numbers. Circles: left hand responses, squares: right hand responses. Synaesthetes' performance is depicted in the left panel, control subjects' performance in the right panel.

DISCUSSION

In classical parity (Dehaene, 1992) or magnitude decision tasks (Bächtold et al., 1998) with centrally presented numerical stimuli, a left hand reaction time advantage is typically observed for relatively small and a right hand reaction time advantage for relatively large numbers. We replicated this effect in three synaesthetes, but instead of presenting numbers, we presented those colors regularly evoked as a concurrent synaesthetic percept accompanying the observation of an achromatic number. This result, although merely descriptive, suggests the presence of a "SCARC effect" (*Spatial-Chromatic Association of Response Codes*) in individuals with digit-color synaesthesia. No SCARC effect was present for the control subjects despite the fact that they had learned the synaesthetes' digit-color associations to a criterion of flawless reproduction performance. These findings thus suggest that subjects did not simply "translate" the centrally presented colors into the associated digits. It also indicates that, in non-synaesthetes, stimulus-response compatibilities in representational space only occur when the association between symbols and spatial locations are explicitly learned (Bächtold et al., 2000).

CONCLUSIONS

The present findings are clearly of a preliminary nature, i.e. they need to be confirmed in larger samples, and statistical analyses seem indispensable.

Yet the pattern of data presented here questions the universality of the law of strictly unidirectional digit-color associations (digits evoke specific colors, but the respective colors do not evoke any number percept). The fact that in most cases this law is experienced at a phenomenal level (but see Baron-Cohen et al., 1996; Cytowik, 1998 for exceptions) does not preclude the possibility that colors cannot evoke an at least implicit numerical association. By analogy, we note that patients with unilateral neglect after right parietal lesions often complain about their limited exploration of left-sided space. To our knowledge, they never complain about difficulties in retrieving specifically small numbers (i.e., relatively "left-sided numbers", by inference). However, such difficulties do in fact exist, as we recently showed with an achromatic SNARC paradigm (Vuilleumier et al., 2004). The synaesthetes tested in the present experiment explicitly denied the presence of bi-directionality in their everyday synaesthetic experience. Perhaps the paradigm introduced here could prove even more informative when administered to those rare synaesthetes with a *conscious* experience of bi-directionality.

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