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Short Communication

Synesthesia: When colors count

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Abstract

A tacitly held assumption in synesthesia research is the unidirectionality of digit–color associations. This notion is based on synesthetes' report that digits evoke a color percept, but colors do not elicit any numerical impression. In a random color generation task, we found evidence for an implicit co-activation of digits by colors, a finding that constrains neurological theories concerning cross-modal associations in general and synesthesia in particular.

Theme: Neural basis of behavior
Topic: Cognition

Keywords: Cross-modal; Digit–color synesthesia; Random number generation; Directionality

The orange ray of the spectrum and the buzz of the gnat (which never rises above the second A), affect me with nearly similar sensations. In hearing the gnat, I perceive the color. In perceiving the color, I seem to hear the gnat.

Edgar Allan Poe, "Marginalia Part I" Democratic Review, November 1844, pp. 484–494, p. 490.

In contrast to this first-hand account by the famous American writer, most synesthetes' cross-modal associations are described as working exclusively in a one-way direction. For instance, in people with digit–color synesthesia, viewing a digit (say, 7) automatically elicits a simultaneous color percept (say, blue). Yet, however hard a synesthete may stare at the blue sky, she will never detect the digit 7 up there; digit-associated colors do not produce any numerical impression [6,7]. To our knowledge, the issue of the unidirectionality of synesthetic associations, although addressed in single case reports [1], has not yet been the subject matter of an empirical study. The possibility remains that, even if synesthetic associations are experienced as unidirectional on a conscious level, "covert bidirectionality" may be nevertheless demonstrable on the level of implicit processing. We set out to investigate this possibility by employing a random generation paradigm [2].

When human subjects generate a random sequence of numbers (such as to mimic the rolls of dice, "Mental Dice Task") [2], they produce too few repetitions of a particular digit on consecutive trials (e.g., 5 followed by 5), and too much counting in steps of one (e.g., 5 followed by 6, 3 followed by 2). This latter bias reflects interference by over-learned and highly automatized rules, i.e., forward and backward counting. Using a modified random generation paradigm that required naming synesthetic *colors* instead of digits, we predicted the characteristic counting bias to be observed only in synesthetes, but not in non-synesthetes. This would be because on naming a color associated with, say, the digit 4, the color associated with either digits 3 or 5 would have a higher probability of occurrence due to the postulated bidirectional automaticity of digit–color associations.

We administered a color-modified version of the Mental Dice Task to 20 digit–color synesthetes (mean age = 37.3 years, 17 women) and 20 non-synesthetes (matched for

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gender, age, and education). History of psychiatric and neurological disease was checked with an abbreviated neuropsychiatric inventory; one of the synesthetes reported epileptic seizures, another reported a history of unexplained fainting-attacks. All synesthetes became aware of their synesthesia in early childhood.

Synesthetes were recruited by adds in a local newspaper and were asked on first contact to paint the colors they associated with the digits 1 to 9 on white paper (A4 format). Matched non-synesthetic subjects were recruited among acquaintances and people attending a local recreational area.

Synesthetes selected the colors they associated with the digits 1 to 6 from a PC color palette (Fig. 1a). Brief verbal labels were agreed upon in the case of idiosyncratic designations (e.g. "dark blue" for "late-evening-sky bluish black"). Pair-matched control subjects learned the 6 digit–color associations prior to the experiment, and perfect performance (in both directions) was established at the day of testing. All subjects then named (eyes closed) the 6 color labels in a sequence as random as possible (66 trials at a rate of approximately 1 Hz). In addition, 50 computer-generated sequences were obtained using the pseudo-random generation algorithm provided in Ref. [8]. For each sequence, we calculated the number of color repetitions and that of color-pairs representing adjacent digits ("counts"; Fig. 1b).

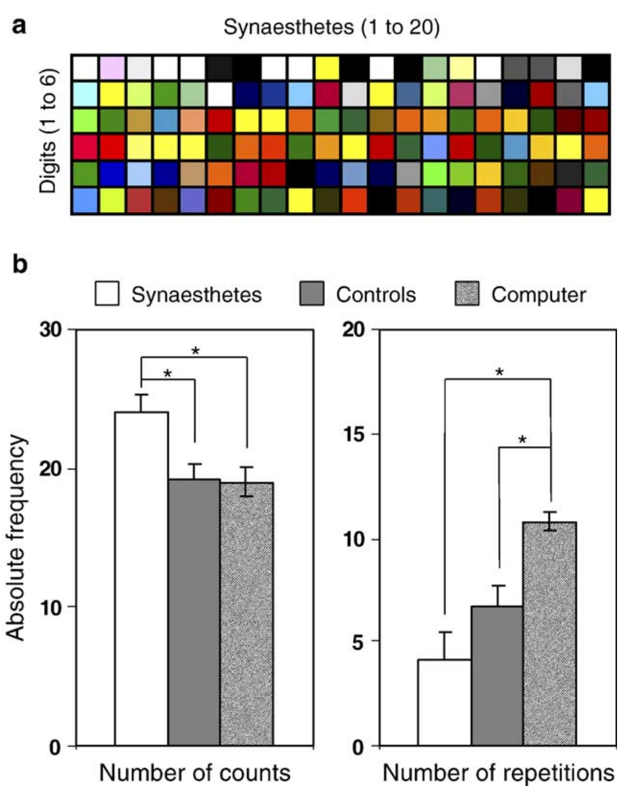

Fig. 1. Synesthetic colors and random color generation performances of synesthetes and controls. (a) Digit–color associations. The columns correspond to 20 synesthetes; the rows to individually associated colors for the digits 1 (top)–6 (bottom). (b) Mean (±1 SE) number of counts (left panel) and of repetitions (right panel) for sequences generated by synesthetes, controls, and a computer. $*P < 0.01$.

One year later, synesthetes painted the colors they associated with the digits 1 to 9 on white sheets of paper a second time (three of them were no longer available). To test the consistency of the synesthetic associations, two independent judges were then confronted with the 20 original and the 17 new sheets and had to pair the corresponding sheets of an individual. This matching was 100% correct for both judges. No task characterizing the perceptual basis of our synesthetes' digit–color associations (e.g., [5]) was administered, an omission pointed out by one referee, who would have considered such assessment indispensable.

Two one-way ANOVAs with group (synesthetes, controls, computer) as between-subjects factor revealed significant group effects (number of counts: $F_{2,87} = 8.99$, $P < 0.01$; number of repetitions: $F_{2,87} = 20.64$, $P < 0.01$). Two-tailed post hoc Scheffé tests indicated that the sequences generated by the synesthetes deviated from the computer-generated sequences in the number of counts ($P < 0.01$) and repetitions ($P < 0.01$), whereas the sequences generated by the controls deviated from those generated by the computer only in the number of repetitions ($P < 0.01$). Crucially, synesthetes showed a significantly higher number of counts than controls ($P < 0.01$). Thus, in randomizing digit-associated colors, synesthetes, but not controls, showed a significant counting bias as it is known from traditional random number generation tasks.

This finding rules out that synesthetic digit–color associations are established solely on the grapheme level. It points to an automatic activation of relational properties of numbers by the naming of the respective colors. Importantly, this activation was not observed in the controls, indicating that short-term associate learning is not sufficient to establish a similarly automatic binding. Even if experienced as unidirectional on a conscious level, the finding of "counting in colors" implies an implicit, unconscious co-activation of digits by synesthetic colors. This covert bidirectionality of synesthetic associations extends the relevance of our findings beyond the context of synesthesia. Studies of brain plasticity after the loss of sensory function have provided evidence for capacities of functional circuits that go beyond those observed in the intact brain. For instance, tactile discrimination during Braille reading in the early blind is reportedly mediated by the visual cortex [3], without, however, being accompanied by the patient's phenomenal experience of "seeing" what her fingertips touch. Currently, this dissociation between the physiological evidence for cross-modal sensory integration and subjects' introspective report is the focus of philosophical speculations about the neural correlates of perceptual awareness [4]. However, its relevance to the recovery of function after neurological damage has not been fully appreciated. In focusing on aspects of bidirectionality, synesthesia research could contribute to both philosophical issues and practical questions of neural repair. In the narrowest context of digit–color synesthesia, we might wish to muse first about the pressing question of what prevents the digit 7 in the blue sky from reaching the synesthete's awareness.

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References

[1] G. Beeli, M. Esslen, L. Jäncke, When coloured sounds taste sweet, Nature 434 (2005) 38.

[2] P. Brugger, Variables that influence the generation of random sequences. An update, Percept. Mot. Skills 84 (1997) 627–661.

[3] L.G. Cohen, P. Celnik, A. Pascual-Leone, L. Faiz, B. Corwell, M. Honda, H. Sadato, Functional relevance of crossmodal plasticity in blind humans, Nature 389 (1997) 180–183.

[4] F. Crick, C. Koch, A framework for consciousness, Nat. Neurosci. 6 (2003) 119–126.

[5] T.J. Palmeri, R. Blake, R. Marois, M.A. Flanery, W. Whetsell, The perceptual reality of synesthetic colors, Proc. Natl. Acad. Sci. U. S. A. 99 (2002) 4127–4131.

[6] V.S. Ramachandran, E.M.J. Hubbard, Synaesthesia—A window into perception, thought and language, Consciousness Stud. 8 (2001) 3–34.

[7] A.N. Rich, J.B. Mattingley, Anomalous perception in synaesthesia: a cognitive neuroscience perspective, Nat. Rev., Neurosci. 3 (2002) 43–52.

[8] J.N. Towse, D. Neil, Analyzing human random generation behavior: a review of methods used and a computer program for describing performance, Behav. Res. Meth. Instrum. Comput. 30 (1998) 583–591.