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Synesthetically induced colors evoke apparent-motion perception

Vilayanur S Ramachandran, Shai Azoulai
Center for Brain and Cognition, University of California – San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0109, USA; e-mail: vramacha@ucsd.edu
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Abstract. Synesthesia is a condition in which certain otherwise normal individuals see colors when they hear tones, or, when they look at black-and-white numbers, each number is tinged with a specific color (eg 5 is red and 2 is green). We constructed a display in which a random matrix of 5s had a vertical column of 2s 'embedded' in it. This was shown in frame 1 of a movie, followed by a similar display in frame 2 in which the element locations were uncorrelated but the bar as a whole was shifted horizontally. When normal subjects viewed the display, they just saw random jitter or twinkle; there was no impression of a bar moving horizontally. But, when our subject (JC) who had grapheme – color synesthesia viewed the display, he reported seeing a bar moving left or right depending on the trial. We conclude that, in at least some subjects, a synesthetically induced color that does not exist on the retina can nonetheless influence motion perception.

1 Introduction

A small percentage of otherwise normal people experience synesthesia; a stimulus in one sense modality seems to spontaneously evoke a different sensation. Although there are many types of synesthesia, the most common appear to be sound – color (synesthetes see colors when they hear tones) and grapheme – color (colors are seen when they look at black-and-white numbers). In number – color synesthesia, for instance, each number is seen to be tinged with a specific color, eg 5 is red and 2 is green (Baron-Cohen and Harrison 1997; Galton 1880; Ramachandran and Hubbard 2001a, 2001b, 2003). In at least some synesthetes—sometimes called 'lower synesthetes' or 'projectors'—the color evoked seems to be a genuine sensory experience; the subject claims to 'see' the color, not merely imagine it.

Apparent motion is the illusion of movement seen when two spatially separated objects are presented sequentially in rapid succession (Braddick 1974; Ramachandran and Anstis 1983, 1986). Here, we raise the questions: Can the subjectively evoked color in synesthesia drive apparent-motion perception, even though there is no color information in the retinal image itself? Is the synesthetically induced color evoked sufficiently early in the hierarchy of visual processing that it can serve as a token for motion correspondence?

2 Subjects

2.1 *Synesthete*

JC is a 26-year-old who has normal color vision and has never had any visual or neurological anomalies, except for the grapheme – color synesthesia that he has experienced from early childhood. JC was unusual in that he was a 'lower synesthete', part of a group that represents only a minority of synesthetes (about 15%; see Hubbard and Ramachandran 2005). Given the rarity of the phenomenon, we were able to test only one subject.

2.2 *Controls*

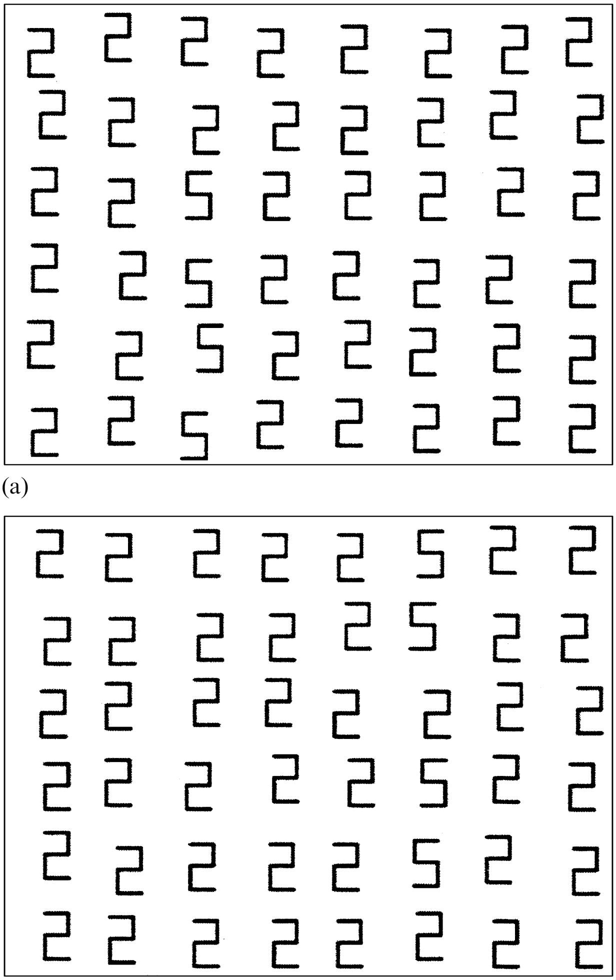
Ten control subjects (six women, four men) were UCSD undergraduate students aged 18 to 22 years. They were compensated for their time with course credit.

3 Methods

3.1 *Experiment 1*

We began with a four-frame apparent-motion sequence (figure 1). Each frame was composed of an array of 2s, embedded in which was a vertical (or horizontal) bar composed mostly of 5s (figures 1a and 1b). The display was 91.5 cm away and subtended a total width of 18.77 deg. Each grapheme subtended 2.38 deg. The bar was 14.76 deg tall and 1 grapheme wide.

The bar of 5s got shifted horizontally (or vertically) as a whole in successive frames, but the locations of the graphemes were 'jittered' randomly (by up to 0.25 deg vertically and horizontally) so as to be uncorrelated across successive frames. Each frame was flashed for 200 ms and ISI (inter-stimulus interval, in this instance inter-frame interval) was 0.



(a)

(b)

Figure 1. Two successive frames of the apparent-motion sequence. They are shown below each other for clarity but were optically superimposed across frames in the actual experiment. (a) A matrix of randomly laced 2s within which is an 'embedded' shape made up of 5s. The display was 91.5 cm away and subtended a total width of 18.77 deg. Each grapheme subtended 2.38 deg. The bar was 14.76 deg tall and one grapheme wide. (b) Identical in composition to (a) except that the element locations are jittered so as to be completely uncorrelated between (a) and (b), and the central bar made up of 5s is displaced by 11.0 deg.

3.1.1 *Experiment 1—results.* To test for motion perception we compared JC's performance with that of ten normal control subjects. Each subject was shown 20 up or down trials interleaved randomly with 20 left or right trials. Each trial consisted of a four-frame apparent-motion sequence, with each frame lasting for 200 ms and with zero ISI. The task was simply to report the direction of motion if any. The durations were chosen to be long enough to yield synesthetic colors and 'long-range' apparent motion (Braddick 1974; Ramachandran and Anstis 1986). Controls' performance was 26% $\pm$ 2.75% SD, ie at chance level. JC's performance was 100%. This provides unambiguous evidence that synesthetically evoked colors can provide an input for motion perception even though the colors do not exist in the image.

Is it possible that JC was simply reporting the change in location of the embedded bar rather than actually seeing motion? This seems unlikely for two reasons. First, none of the normal subjects could do the task. Second, JC spontaneously volunteered that he was quite literally seeing the motion and he confirmed this when questioned after the experiments.

3.2 *Experiment 2*

To demonstrate this unequivocally, we showed JC just two frames with stimulus duration kept constant at 100 ms and ISI varied over a range. The spatial separation between targets was kept constant at 11 deg. Normal subjects see motion only over a restricted range of time intervals; 0 to 175 ms ISI for any fixed visual angle. Smaller intervals yield simultaneity and longer intervals yield temporal succession rather than motion. We found this to be true for JC when we randomly varied the time interval between two frames and measured thresholds for transition from simultaneity to motion to mere succession. The ISI was varied from 0 to 500 ms; 30 readings were obtained.

3.2.1 *Experiment 2—results.* Thresholds for simultaneity and succession were 117 ms and 323 ms, respectively, and optimal motion was seen at 267 ms (mean). Two weeks later there was a surprise re-test of the experiment to check for consistency. Upon re-test, thresholds for simultaneity and succession were 112 ms and 317 ms, respectively and optimal motion was seen at 263 ms (mean). Since JC had no prior knowledge of motion psychophysics and since he could not have 'memorized' and remembered his own thresholds for a week, this observation provides compelling evidence that he was indeed seeing motion. Indeed the very fact that distinct simultaneity versus motion versus succession thresholds could be obtained argues against the possibility that he was not really seeing motion at any speed. (For how can a subject consistently report a *transition* from motion to succession unless he was seeing motion?) The thresholds seem rather long but may reflect the additional processing time required for synesthetic colors.

3.3 *Experiment 3*

Finally we tested JC's apparent-motion thresholds with real colors as a comparison to the threshold for synesthetically induced colors. We created matrices identical to those in experiment 2 (figures 1a and 1b), but with real physical colors instead of synesthetic ones (the colors were chosen to be as close of a match with the synesthetically evoked colors as possible). The 2s and 5s rotated 90° so as not to elicit synesthetic colors that might enhance or 'clash' with the real colors. We then repeated experiment 2 using these new matrices.

3.3.1 *Experiment 3—results.* This time the thresholds for simultaneity and succession for real colors were 66 ms and 250 ms, respectively.

4 Conclusion and discussion

We conclude that colors induced through graphemes can support 'long-range' motion even though they do not exist in the retinal image. Given the rarity of 'lower' synesthetes—they constitute only 12% to 15% of synesthetes as a whole (Hubbard and Ramachandran 2005)—we were able to test only one subject. As such, these results should be regarded as a 'single-case study', but this does not vitiate their importance (Broca's aphasia, Wernicke's aphasia, and 'blindsight' were all originally based on single cases).

Additional experiments are needed to determine whether the perceived color is driving the motion directly or indirectly by defining the 'form' that then drives motion. But in either case the occurrence of clear temporal thresholds for transition between simultaneity, motion, and succession, and subsequent test/re-test verifiability of the thresholds rules out the possibility that JC was just inferring change of location of colors rather than actually seeing motion. One would not expect to elicit a *transition* from motion to succession unless motion was being seen.

What parts of the brain are involved in synesthesia? In fMRI experiments, we have recently shown (Hubbard et al 2005) that even black-and-white graphemes evoke activity in color area V4 in the fusiform gyrus of synesthetes. One wonders if in subjects like JC there would be additional activation of the 'motion area' MT when presented with apparent-motion displays such as figure 1. We conclude that colors evoked entirely in the mind of a synesthete can provide an input to motion perception even though the colors do not exist physically on the retina.

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