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著者	HIDAKA Souta, SHIGETA Remi, KAWACHI Yousuke, SAKUTA Yuiko, GYOBA Jiro
journal or publication title	Tohoku psychologica folia
volume	66
page range	68-74
year	2008-03-31
URL	http://hdl.handle.net/10097/54692

Tohoku Psychologica Folia
2007, **66**, 68－74

Speed and Consistency of Sound-Color Association in a Colored-Hearing Test

Souta HIDAKA (日高聡太)[1], Remi SHIGETA (重田礼美)[1],
(*Tohoku University*) (*Tohoku University*)
Yousuke KAWACHI (河地庸介)[1], Yuiko SAKUTA (作田由衣子)[2],
(*Tohoku University*) (*Waseda University*)
and Jiro GYOBA (行場次朗)[1]
(*Tohoku University*)

Synesthesia is the phenomenon in which the stimulation of one sensory modality results in perception in another modality, namely, unstimulated modality. Colored hearing is a synesthesia in which sound stimulation induces visual color perception. The current research investigated the speed and consistency of sound-color association in a colored-hearing test by using a color search task. The results showed that the reaction time (RT) of the colored-hearing group was faster than that of the control group. We also found that the colors selected by the colored-hearing group were more consistent than those selected by the control group. These findings suggested that in colored-hearing synesthetes, automatic and consistent sound-color association occurs in the perceptual stage of processing.

Key words: colored-hearing, color search task, reaction time, number of selected colors, amount of information

Introduction

Synesthesia is the phenomenon in which the stimulation of one sensory modality causes perception in another modality, namely, the unstimulated modality (Ramachandran & Hubbard, 2003). Most people can linguistically express a multimodal sensation such as "red is a warm color." Synesthesia is distinguishable from such ordinary mediated associations because synesthetes experience multimodal sensations as real percepts (Cytowic & Wood, 1982a).

Colored hearing is a cross-modal synesthetic perception in which sound stimuli induce visual color perception. Marks (1975) reported that colored-hearing synesthetes could perceive a variety of colors with the physical transitions of tone or pitch. Cytowic and Wood (1982b) also found that synesthetes exhibit highly consistent associations between sounds and colors as compared to people without colored hearing.

1 Department of Psychology, Graduate School of Arts and Letters, Tohoku University, 27-1, Kawauchi, Aoba-ku, Sendai 980-8576, Japan; Email: hidaka@sal.tohoku.ac.jp
2 Faculty of Human Sciences, Waseda University, Mikajima 2-579-15, Tokorozawa, 359-1192, Japan

Grapheme-color synesthesia is a synesthesia in which graphemes such as letters or number symbols induce color perception. It was reported that grapheme-color synesthetes could immediately detect a target letter from among distractors in a visual search task by using synesthetic colors as "pop out" cues (Laeng, Svartdal, & Oelmann, 2004; Palmeri, Blake, Marois, Flanery, & Whetsell, 2002). Hubbard, Arman, Ramachandran, and Bonyton (2005) found that grapheme-color synesthetic perception could aid in texture segregation performance and reduce the effect of crowding. In addition, they reported that synesthetes with better performance on these behavior tasks showed greater brain activity in early visual areas (V1, V2, V3, and hV4). These findings indicated that grapheme-color perception occurs in the perceptual, relatively early stage of processing (Hubbard & Ramachandran, 2005).

Compared to the number of studies on grapheme-color synesthesia, there are few psychophysical studies on colored-hearing synesthesia. In order to investigate whether colored-hearing synesthetic perception occurs in the perceptual stage of processing, the current research investigated the speed of sound-color association in colored hearing by using reaction time (RT) as an index. It could be assumed that colored-hearing synesthetic sensation occurs as a real percept, whereas the association between colors and sounds are cognitive or conceptual for people without colored hearing (Cytowic & Wood, 1982b). Therefore, we predicted that colored-hearing synesthetes would perceive "pop-out" colors invoked by sounds in a color search task so that their RTs would be faster than those of non-synesthetes. We also investigated the consistency of sound-color association in colored hearing by using the number of selected colors and the amount of information of sound for color as indices.

Method

Participants

In order to recruit participants with colored hearing, we distributed a questionnaire to 151 students of Tohoku University (70 males and 81 females). The questionnaire comprised 16 items: 10 were used in Ulich (1957) and 6 were originally created based on the findings of Mills, Boteler, and Larcombe (2003). Representative examples of our items are as follows: "Do you experience seeing colors when you hear sounds or music?" and "Do you imagine colors when you hear sounds or music?" The participants were asked to rate each item by using a five-point scale. Based on the rating scores, we classified 13 people (four males and nine females) as "colored-hearing synesthetes," 36 people (14 males and 22 females) as "moderate colored-hearing synesthetes," and 102 people as "non-synesthetes." In the experiment, eight people (two males and six females) were participants of the "colored-hearing group." Two of them were colored-hearing synesthetes and six were moderate colored-hearing synesthetes. Ten non-synesthetes (four males and six females) were control group participants. All the participants had normal or corrected-to-normal vision and normal hearing. Further, we confirmed that they had normal color vision by the Ishihara color blindness test.

Apparatus

The stimuli were presented on a CRT display (Mitsubishi, Diamond M2, 17 inches) with a

Table 1 Hues, chromatic coordinates, and luminance values of color stimuli used in the present study.

Color	Chromatic coordinates X-axis	Chromatic coordinates Y-axis	Luminance (cd / m^2)
Blue	0.19	0.19	12.36
Brown	—	—	7.52
Glaucous	0.25	0.38	21.37
Green	0.28	0.50	29.24
Olive	0.40	0.52	46.32
Orange	0.51	0.43	43.72
Pink	0.43	0.36	46.95
Purple	0.31	0.24	11.18
Red puple	0.46	0.30	14.95
Red	0.57	0.36	21.80
White	0.30	0.32	112.80
Yellow	0.45	0.48	73.15

resolution of 1280 × 1024 pixels and a refresh rate of 70 Hz. A customized PC (Dell Dimension 8250) with E-prime (Psychology Software Tools, Inc.) was used to control the experiment. The participants held their heads on a chin rest. Two speakers were fixed on either side of the display.

Stimuli

Sounds. Seven single pitches of piano tones (C, D, E, F, G, A, and B) created by the PC software were used as sound stimuli. The duration of each sound was 1000 ms. The sound pressure of each sound was approximately 50 dB.

Colors. We choose 12 colors from the Munsell color system including those reported as synesthetic colors in grapheme-color synesthesia (Mills et al., 2003; Laeng et al., 2004). Hues, chromatic coordinates, and luminance values of the color stimuli are shown in Table 1. Each color stimulus (0.65 × 0.65 deg) was presented as a matrix of 3 × 4 with a gap of 0.4 deg. The visual angle of the color matrix was within 5 deg because it was reported that synesthetic color perception does not usually occur in peripheral vision (Laeng et al., 2004). The observation distance was 114.6 cm.

Procedure

Each trial began with the presentation of a white circle (0.5 deg) at the center of the display. The participants were asked to move the mouse cursor to the center of the circle and press the left mouse button. After 1000 ms, a matrix of 12 color stimuli was presented. The position of each color stimulus was randomized in each trial. Followed by a 1000-ms interval, one of the seven sound stimuli was presented. The sound stimulus was randomly selected in each trial and counterbalanced across trials. The participants localized the mouse cursor on one of the color stimuli that they perceived as being associated with the sound stimulus, and pressed the left mouse button. They were asked to make their responses as soon as possible. The sound stimulus was presented repeatedly until the button was pressed. The interval between the initial onset of the sound stimulus and the press of the button was recorded as the RT. The selected color was also recorded.

The experiment comprised 280 trials (sounds (7) × repetitions (40)). In order to attenuate the selection bias of the participants, the experiment consisted of two day sessions. The intervals between the sessions ranged from five to seven days. In each session, the participants conducted 10 practice and 140 main trials; the main trials were divided into two parts with a 5-minute break between the parts.

Results

Reaction time

We analyzed the RTs within ± 2 SDs from the mean for each participant. The mean RT in the color search task for the colored-hearing group was 2122 ms and that for the control group was 3248 ms (Figure 1). A two-tailed t-test revealed a significant difference in RT between the two groups ($t(16) = -2.15, p < .05$).

Number of selected colors and amount of information

We calculated the number of selected colors for each sound stimulus. The mean number of colors selected by the colored-hearing group was 2.71 and the mean number of colors selected by the control group was 4.43 (Figure 2). A two-tailed t-test revealed a significant difference in the number of selected colors between the two groups ($t(16) = -2.93, p < .01$). We further calculated the amount of information of sounds for colors in order to confirm the uniformity of sound-color association. A greater amount of information implies higher uniformity. The mean amount of information for the colored-hearing group was 1.85 bits and that for the control group

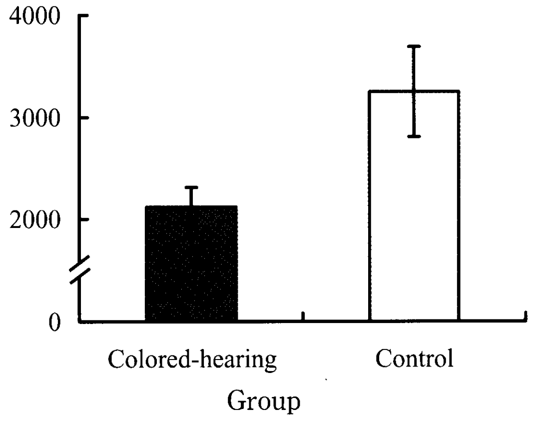

Figure 1. Results of RT. The abscissa denotes the type of group, and the ordinate denotes the mean RT. Error bars denote the mean standard error.

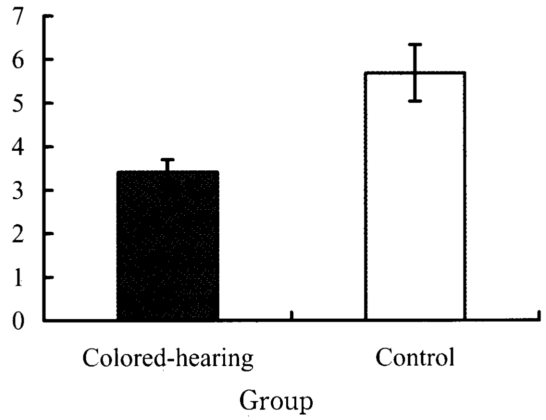

Figure 2. Results of the number of selected colors. The abscissa denotes the type of group, and the ordinate denotes the mean number of selected colors. Error bars denote the mean standard errors.

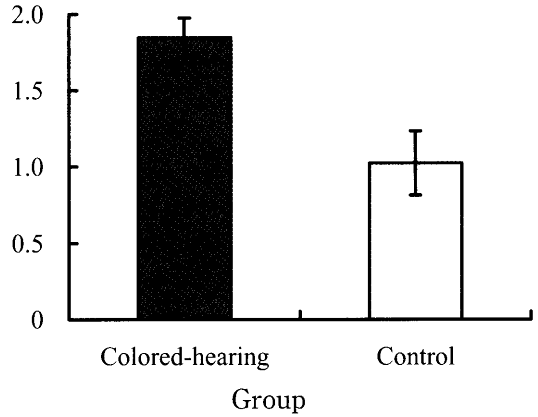

Figure 3. Results of the amount of information of sounds for colors. The abscissa denotes the type of group, and the ordinate denotes the mean amount of information. Error bars denote the mean standard errors.

was 1.02 bits (Figure 3). A two-tailed t-test revealed a significant difference in the amount of information between the two groups ($t(16) = 3.11$, $p < .01$).

Discussion

The current research psychophysically investigated the speed and consistency of color-sound association in colored hearing by using a color search task. The results showed that the RT of the colored-hearing group was faster than that of the control group. This finding indicates that colored-hearing synesthetes can immediately perceive "pop out" colors induced by sound stimulation. In line with the previous findings on grapheme-color synesthesia (Hubbard & Ramachandran, 2005; Laeng et al., 2004; Palmeri et al., 2002), the present finding implies that colored-hearing synesthesia occurs in the perceptual, relatively early stage of processing.

We also found that the number of colors selected by the colored-hearing group was smaller than that selected by the control group. In addition, the amount of information of sounds for color for the colored hearing group was found to be greater than that for the control group. From these findings, we confirmed that colored-hearing synesthetes exhibit higher consistency between sounds and colors (Cytowic & Wood, 1982b).

Although the existence of synesthesia has been known for approximately 250 years, research on synesthesia by using objective, experimental methods was never conducted till the 1970s (Harrison & Baron-Cohen, 1995). In particular, the many characteristics of colored-hearing synesthesia remain unclear. Our preliminary questionnaire survey revealed that a relatively large population experiences some colored-hearing synesthetic sensations. This fact indicated that the study of colored hearing should no longer be limited to the framework of the case study method. It was suggested that not only the pitch of sounds but also loudness or tone induce a variety of synesthetic color perceptions (Marks, 1975; Mills et al., 2003). Thus, further investigation needs to be conducted on whether synesthetic color perception invoked by loudness or tones also occurs during the perceptual stage of processing. Recently, an fMRI study demonstrated that grapheme-color synesthetic perception activated early visual areas (Hubbard et al., 2005). Our present finding suggests that similar brain activities might be observed for colored-hearing perception. Psychophysical or neurophysiological studies would be useful to elucidate the characteristics of colored-hearing synesthetic perception.

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(Received November 19, 2007)
(Accepted January 23, 2008)