博士論文

Semantic Sensory Correspondence between Color and Shape

(色と形状との意味的対応に関する研究)

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Semantic Sensory Correspondence between Color and Shape

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by

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Abstract

Kandinsky proposed a correspondence theory between color and shape, wherein circles, squares, and triangles are associated with blue, red, and yellow, respectively. These color-shape associations have been studied by artists and researchers for over a century. However, why specific color-shape associations exist, and the effect of color-shape associations with other perceptual/cognitive dimensions are as yet unknown. This thesis explored the general associations between colors and shapes using both direct and indirect experimental methods, among normal hearing and deaf people, to examine the nature of color-shape associations and the interactions with hearing sound effect.

The first study used an explicit matching task, in which participants were asked to choose which color best matched a variety of shapes. Results showed that Japanese people systematically associated shapes with colors (e.g., circle-red, triangle-yellow, square-blue), and these color-shape associations were consistent with those of Italian participants. Moreover, most of those color-shape associations could be interpreted by the presence of semantic information common to colors and shapes (e.g., warm/cold).

The second study used an indirect behavioral method, namely implicit association tests (IATs), to examine color-shape associations. Results demonstrated that color-shape associations were encoded by participants, and were strong enough to influence perceptual information processing and behavioral task performance. This provides the first evidence that color-shape associations can be measured by an indirect behavioral experimental method.

The third study investigated whether the sound or hearing experience plays a role in color-shape associations by comparing color-shape associations in deaf people with hearing people. Results showed that deaf and hearing people exhibited similar patterns of color-shape

associations (i.e., circle-red, triangle-yellow, square-blue) in the explicit questionnaire task. However, deaf people showed less pronounced congruency effect of color-shape associations than hearing people in the indirect behavioral tasks. Those results suggested that auditory experiences influence color-shape associations. Based on these results, semantic sensory correspondence was proposed as a means to interpret color-shape associations in both deaf and those with normal hearing.

Finally, whether semantic information also influences relationships in other domains, such as cross-preferences for colors and shapes was investigated. Results showed people who preferred some simple/complex shapes also tended to prefer some light/dark colors, and these cross-preferences might be explained by some semantic information (e.g., simple/complex, light/dark).

Taken together, these results suggested that Japanese color-shape associations could be verified by both direct and indirect behavioral experimental methods. Semantic sensory correspondence between colors and shapes could explain color-shape associations, the influence of hearing sound effect on color-shape associations, and cross-preference for color and shape.

Table of contents

List of figures

List of Tables

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1. Introduction

Background

Color and shape are the two basic elements in visual design and art creation. Artists and researchers have spent considerable efforts examining the general associations between colors and shapes. Wassily Kandinsky, a renowned abstract painter, first proposed a fundamental correspondence theory between basic shapes and primary colors, such that circles, squares, and triangles are associated with blue, red, and yellow, respectively (Kandinsky, 1912, 1947). He claimed that some colors are emphasized by certain shapes, whereas others are hampered by them. For instance, sharp colors are stronger in sharp shapes (e.g., the yellow-triangle link), and the effect of deep color is emphasized by round shapes (e.g., the blue-circle link). In 1923, Kandinsky used an empirical approach to investigate this correspondence theory among his fellow art students and teachers at the Bauhaus. He designed a questionnaire that instructed participants to match the three primary colors (i.e., yellow, red, blue) to the three basic shapes (i.e., circle, triangle, square), and to give a reason for their choices. Most of the participants made the blue-circle, red-square, and yellow-triangle matches, confirming his correspondence theory. He argued that the correspondence between colors and shapes was mediated by an inner relationship between colors and angles. He proposed three types of angles and associated relationships: an acute angle is inherently active and aggressive, a right angle is chilly, and an obtuse angle is cold and calm. Therefore, a triangle with three acute angles should be matched with an active and aggressive color, i.e., yellow; a circle, characterized by an expansion of the obtuse angle, is cold, and should be matched with a cold color, i.e., blue; a square, formed by four right angles, should be matched with the color red, which is between yellow and blue. Thus Kandinsky's correspondence theory (blue-circle, red-square, and yellow-triangle) is based on the assumption that there exists certain semantic information common to colors and shapes, which leads to the general associations between them.

Kandinsky's correspondence theory became influential in art and design theory ever since it was proposed, however, it evoked lots of opposites from fellow artists and researchers. Indeed, some revisited the color-shape associations but found different results (e.g., Albertazzi et al., 2013; Dumaitrescu, 2003, 2011; Jacobsen, 2002; Jacobsen & Wolsdorff, 2007; Kharkhurin, 2012; Lupton & Miller, 1993). For example, Jacobsen (2002) used a modified version of Kandinsky's questionnaire with German participants and found assignments of red to triangle, blue to square, and yellow to circle. Jacobsen suggested that everyday knowledge influences these color-shape associations. For example, traffic yield signs might lead to the red-triangle association, and the yellow-sun associations might lead to the yellow-circle linkage. Jacobsen and Wolsdorff (2007) also examined color-shape associations in a sample of art experts. Their results showed that individuals have their own color-shape combination preferences, disagreeing with Kandinsky's correspondence theory. Dumitrescu (2011) asked participants to rate the appropriateness of nine colored shapes (3 colors × 3 shapes) and nine colored three-dimensional shapes using a five-point scale. Results suggested associations between circles or spheres with red, and squares or cubes with blue, which are opposite to the associations in Kandinsky's theory. Kharkhurin (2012) tested Kandinsky's correspondence theory using both explicit and implicit experimental methods. He first directly asked participants about color-shape assignment. The associations reported (e.g., square-blue) did not support Kandinsky's theory. Subsequently, he used implicit experimental methods, by a color-shape priming technique and a color-shape recognition test. However, the implicit experiments also failed to reveal any color-shape associations in line with Kandinsky's correspondence theory. Makin and Wuerger (2013) used a series of three implicit association tests (IATs) to investigate three pairs of color-shape combinations. Participants were asked to press one of two keys to discriminate a color or shape stimulus. Response times should theoretically be faster when the same key was used to report colors or shapes that were associated within a given stimulus, rather than stimuli consisting of unassociated colors or shapes, according to Kandinsky's color-shape associations. Results did not show clear evidence for correspondence theory, with only a marginal effect for one pair of combinations among the three combinations they tested.

However, there are some studies that have provided support for Kandinsky's color-shape associations. For example, Hantzsch (1935) carried out an experiment with pupils from the first to fourth grade of an art school. The pupils were asked to color the primary shapes (circle, square, and triangle) and the associated three-dimensional shapes (sphere, cube, and pyramid). Hantzsch found that 36% and 37% of pupils chose red for square and cube, respectively; 30% and 38% chose yellow for triangle and pyramid, respectively; and 21% and 28% choose blue for circle and sphere, respectively. However, these results were obtained from art students, who had elementary knowledge of colors and shapes. Holmes and Zanker (2008) used a gaze-driven evolutionary algorithm to investigate preferred combinations of colors and shapes. They found consistent preferences for color-shape combinations within individual participants, but only a weak preference for the triangle-yellow combination across participants. Most recently, Albertazzi et al. (2013) examined the naturally biased color-shape associations using an explicit matching task among Italian people. Participants were instructed to choose which hue best matched various geometric shapes from Natural Color System Hue Circle. Albertazzi et al. (2013) observed that participants systematically matched some shapes with specific colors. For example, the circle and square were associated with red, and the triangle was associated with yellow, which partially supported Kandinsky's correspondence theory. Albertazzi et al. (2013) suggested that the “warmth” and “lightness” might determine these color-shape associations.

Taken together, these aforementioned studies, using direct or indirect experimental methods, examining Kandinsky’s correspondence theory or the general color-shape association, indicated the existence of certain associations between colors and shapes. Moreover, the color-shape associations are likely not independent but interact with other forms of perceptual/cognitive information such as graphemes, sounds, and semantics.

Studies on grapheme-color synesthesia have found that some letters or digits are consistently associated with particular colors (Asano & Yokosawa, 2011, 2012; Barnett et al., 2008; Rich, Bradshaw, & Mattingley, 2005; Simner et al., 2005; Spector & Maurer, 2011). Some of those grapheme-color associations appear to be stemmed from learning a written language (e.g., *b* is associated with blue), whereas others might be related to the visual characteristics of grapheme shapes. For example, round versus angular or open versus closed characteristics have been reported to affect grapheme-color associations. (Brang, Rouw, Ramachandran, & Coulson, 2011; Jurgens, Mausfeld, & Nikolic, 2010; Jurgens, Nikolic, 2012). Graphemes with similar shapes evoke similar color correspondences (Brang, Rouw, Ramachandran, & Coulson, 2011). Witthoft and Winawer (2006) reported that a synesthetic color depended on the font and the case of letters. Furthermore, individuals without synesthesia also exhibited grapheme-color associations similar to individuals with synesthesia, and some of those associations were influenced by the visual shapes of graphemes (Lau, Schloss, Eagleman, & Palmer, 2011; Simner et al., 2005; Spector & Maurer, 2008, 2011).

Previous studies have shown that visual colors express semantic information. For example, the color red may convey impressions such as love, power, and passion; blue may convey cold and calmness; yellow may convey aggression and warmth; and green may convey peace, hope, and nature (D'Andrade, & Egan, 1974; Elliot & Maier, 2007; Ou, Luo, Woodcook, & Wright, 2004; Stone & English, 1998). In Particular, colors can be described in terms of temperature, such as "warm" or "cold"; longer-wavelength colors (e.g., red and yellow) likely evoke warm perceptions, while short-wavelength colors (e.g., green and blue) likely lead to cold perceptions (Ballast, 2010; Whitfield & Wiltshire, 1990). Studies on visual shape symbolism have reported that shapes can also express specific semantic meanings. For example, round shapes (e.g., circles) tend to be associated with warmth and softness; shapes bounded by straight lines (e.g., squares) are associated with coldness and hardness (Liu, 1997; Liu & Kennedy, 1993; McManus & Wu, 2013; Oyama & Haga, 1963); shapes with sharp angles may reflect feelings of threat and danger (e.g., sharp shapes might be associated with knives; Bar & Neta, 2006; Larson, Aronoff, & Steuer, 2012). Taken together, we can see that colors can be warm or cold, light or dark, and so on, while shapes can be sharp or round, heavy or light, and so on. However, it is conceivable to imagine a warm or cold shape, or a heavy or light color. Some colors and shapes may convey overlapping or associated semantic information (e.g., both red and circle are associated with warmth). As Albertazzi et al. (2013) suggested that the "warmth" and "lightness" of colors could lead to color-shape associations, it might be possible that some common or shared semantic information between colors and shapes leads to the general associations between them.

People show implicit cross-modal associations between visual features and sound (Marks, 1987; Spence, 2012; Evans & Treisman, 2010; Ward, Huckstrp, & Tsakanikos, 1997; Kohler, 1947). For example, when asked to match nonsense words like "bouba" or "kiki" to angular or rounded shapes, more than 95% of people agreed that "bouba" matched rounded shapes, and "kiki" matched angular shapes (Kohler, 1929, 1947; Ramachandran & Hubbard, 2001). Furthermore, studies have suggested that people tend to match high-pitched sounds with sharp angular shapes and lighter colors, and low-pitched sounds with rounded shapes and darker colors (Hubbard, 1996; Marks, 1974; Simpson, Quinn, & Ausubel, 1956; Walker et al., 2010; Ward, Huckstep, & Tsakanikos, 2006). Crossmodal sound-color and sound-shape associations indicate that sounds may affect the correspondence between colors and shapes. According to the extensive and bidirectional cross-activations among these sound-visual dimensions, angular shapes should be matched with bright colors (Karwoski, Odbert, & Osgood, 1942; Walker, 2012; Walker & Walker, 2012). Therefore, the auditory information might also influence color-shape associations.

Outline of the thesis

In this thesis, I explore the general color-shape associations, using both direct (i.e., explicit matching task) and indirect experimental methods (i.e., implicit association test) among different groups of people (i.e., deaf individuals versus those with normal hearing), and for different dimensions, such as the natural associations and relationships between preference judgments for colors and shapes.

In Chapter 1, I first introduce the background to the present study, with a review of the prior studies on color-shape associations, and the interaction of these associations with other forms of perceptual/cognitive information, such as grapheme-color associations, crossmodal interactions between sound and vision, and semantic information by colors and shapes.

In Chapter 2, I describe the first study, which replicated Albertazzi et al. (2013), using an explicit matching task to examine the general associations between colors and shapes in Japanese people. Experiment 1 showed that Japanese people have specific color-shape associations, consistent with those of Italians. Then, I further investigated the possible interpretations of these color-shape associations by means of a semantic rating task. Common semantic information (e.g., warm/cold) between colors and shapes might lead to color-shape associations.

In Chapter 3, I adopt an indirect behavioral experimental method — the implicit association test — (IAT; Greenwald, McGhee, & Schwartz, 1998) to examine color-shape associations. I first tested Kandinsky's correspondence theory by applying the IAT in Japanese participants, and results showed limited evidence for Kandinsky's color-shape associations. Then, I tested Japanese color-shape associations using the IAT tasks. Results suggested that Japanese people's color-shape associations were encoded and could influence perceptual information processing and task performance using the indirect behavioral method.

In Chapter 4, I explore color-shape associations in deaf people using both direct and indirect experimental methods, and compare with those of hearing people. Results by direct questionnaire survey showed that both deaf and hearing people revealed specific color-shape associations, which were consistent with each other. However, results by indirect IAT task showed that deaf people exhibited less pronounced color-shape associations than hearing people, which indicated that hearing experience influence color-shape associations. Based on those results, I proposed semantic sensory correspondence to interpret color-shape associations both in deaf and hearing people.

In Chapter 5, I examine whether semantic information of colors and shapes also account for cross-preference dimensions. The relationships of preferences for colors and shapes based on individual difference showed that people who preferred some simple/complex shapes also tended to prefer some light/dark colors, and the semantic information might also explain it.

In Chapter 6, I summarize the findings and conclusions based on semantic sensory correspondence for colors and shapes.

In summary, the present study contributes to the understanding of color-shape associations, by using direct and indirect experimental methods, and by considering the differences in auditory experience. It demonstrates that semantic sensory correspondence between colors and shapes can interpret the color-shape associations reported here. The studies help understanding of the mechanisms of crossmodal correspondence, and may also be beneficial for product design and advertisement involving colors and shapes.

2. Color-shape associations

2.1 Introduction

Albertazzi et al. (2013) reported that Italian participants naturally associated specific shapes with colors. They instructed participants to choose a most closely related color from the Nature Color System Hue Circle to a geometric shape. Participants systematically chose hue colors for specific shapes. For example, triangles were matched with yellows, and circles and squares were matched with reds. Albertazzi et al. (2013) suggested that the "warmth" and "lightness" of hues determined these color-shape associations. However, it is still unclear to what extent the color-shape associations are shared among different groups of people, such as different cultural populations (e.g., Italian and Japanese). If color-shape associations differ among cultures, this might indicate that the associations are not innate, but instead shaped by culturally specific learning experiences, or by language development. For example, the words "circle", "triangle", and "square" have different phonetics in Italian ("cerchio [/ˈtʃerkjo/]," "triade [/ˈtriade/]," "quadrato [/kwaˈdrato/]") and Japanese ("maru [/'mɑ:ru/]," "sankaku [/sa:nˈka:ku:/]," "shikaku [/ʃiˈka:ku:/]"), which might be a factor in fostering color-shape associations. Consistent color-shape associations between the two cultures would indicate some degree of universality, with the associations little influenced by learning experiences and language development. Instead, the associations might be influenced by visual properties such as the semantic information associated with colors and shapes.

In this chapter, I examine the color-shape associations of Japanese participants, and the cultural difference effect on the color-shape associations, with the aim of understanding the possible reasons for any associations. Experiment 1 replicated Albertazzi et al.'s (2013) study but using Japanese participants. Experiment 2 investigated a possible explanation for these color-shape associations.

2.2 Experiment 1: color-shape associations in Japanese observers

2.2.1 Method

Participants

One hundred and thirty-eight non-synesthesia Japanese college students took part in the experiment (57 females, mean age = 21.3, *SD* = 2.6). All participants had normal or corrected-to-normal visual acuity and normal color vision. This experiment, as well as the subsequent experiments with normal participants, were approved by the institutional review board (IRB) of The University of Tokyo, and conducted in accordance with the ethical standards in the 1964 Declaration of Helsinki. Written informed consent was obtained from all participants in advance.

Apparatus and Stimuli

This experiment referred to Albertazzi et al. (2013) experimental paradigm. Stimuli were displayed on a 15.5-inch LCD color monitor with 1920 × 1080 resolution at a 60 Hz refresh rate controlled by a laptop computer. Participants observed the monitor at a distance of approximately 60 cm. Stimuli consisted of 40 hue-color filled-circles (with a radius of 0.64 cm; 1.22° visual angle) with reference to the Natural Color System Hue Circle Atlas. The color values in Table 1 were measured by PR-655 (Photo Research, Chatsworth, CA, USA) and each color was consecutively measured for 10 times and averaged.

One of 12 basic line drawing shapes, including 8 types of 2-dimensional shapes (circle, triangle, square, rhombus, hexagon, trapezoid, oval, and parallelogram; Fig. 1a) and 4 types of 2D projections of 3D shapes (cone, pyramid, truncated cone, and truncated pyramid; right 3 shapes in Fig. 1a) were presented in the center of the screen. The geometric shapes were all drawn with black lines at a width of 2.6 mm (0.03°) on a white background (90 cd/m^2). I adopted three levels of size and three levels of rotation for the shapes. The three sizes were marked as small, medium, and large. In particularly, the large size was approximately four times the area of the medium sizes, and the small sizes were approximately one-sixteenth the area of the medium sizes. The three spatial rotation levels for each shape were rotated for 0°, 15°, and 345° (except for the circle). Thus, 102 shape stimuli (11 shapes × 3 sizes × 3 rotations + 1 shape × 3 sizes = 102 shapes) were created. A shape stimulus appeared at the center of the screen, and the 40 hue color circles were on a circumference of an imaginary circle with a radius of 10.20 cm (19.40°; Fig. 1b).

Procedure

The experiment was carried out in a dimly lit room (1 lux on the wall). Participants were seated in front of a computer-monitor and instructed to intuitively choose one color from the 40-color patch that most naturally matches the centrally presented shape using a mouse click. The shape stimulus appeared at the center of the screen; after 100 ms, the 40 color circles appeared around the shape. The shape and color circles remained on the screen until a response was made. The next trial started immediately after the response. Each shape was randomly presented and displayed twice over two blocks, resulting in 204 trials. For each trial, the orientation of the color circles was selected pseudo-randomly. The experiment lasted approximately 15 minutes. Experimenters avoided using any color or shape terms during task administration.

Table 1. Hue color information

NO.	Color group	Hue (°)	Lightness*	Chroma*
1	YY	80.2	97.92	129.79
2	YY	76.85	92.16	125.39
3	YR	72.26	87.81	124.31
4	YR	66.91	85.18	126.65
5	YR	65.1	79	121.5
6	YR	62.15	77.04	119.54
7	YR	59.94	75.21	120.28
8	RR	53.19	70.6	107.39
9	RR	49.31	60.06	97.4
10	RR	42.88	51.38	76.81
11	RR	32.35	50.08	64.62
12	RR	7.9	55.52	54.78
13	RB	-3.71	52.72	50.89
14	RB	-33.61	59.77	58.82
15	RB	-47.24	51.51	63.36
16	RB	-62.75	38.81	63.43
17	RB	-69.4	45.09	54.83
18	BB	-89.99	48.47	45.29
19	BB	-101.71	60.38	42.78
20	BB	-115.43	65.08	37.77
21	BB	-141.39	67.04	32.74
22	BB	-149.84	63.15	30.75
23	BG	-167.69	64.95	32.7
24	BG	175.53	63.68	36.16
25	BG	178.42	69.88	38.07
26	BG	178.42	69.87	38.07
27	BG	171.87	69.33	40.3
28	GG	163.94	65.7	42.48
29	GG	161.36	71.22	47.18
30	GG	155.29	72.02	52.48
31	GG	141.66	79.44	62.78
32	GG	126.03	87.56	70.82
33	GY	111.44	95.51	90.31
34	GY	107.97	104.1	92.58
35	GY	103.78	106.9	101.25
36	GY	99.35	106	122.22
37	GY	96.49	109.4	126.11
38	YY	93.22	111.4	128.5
39	YY	90.94	110.9	140.02
40	YY	87.48	106.1	135.53

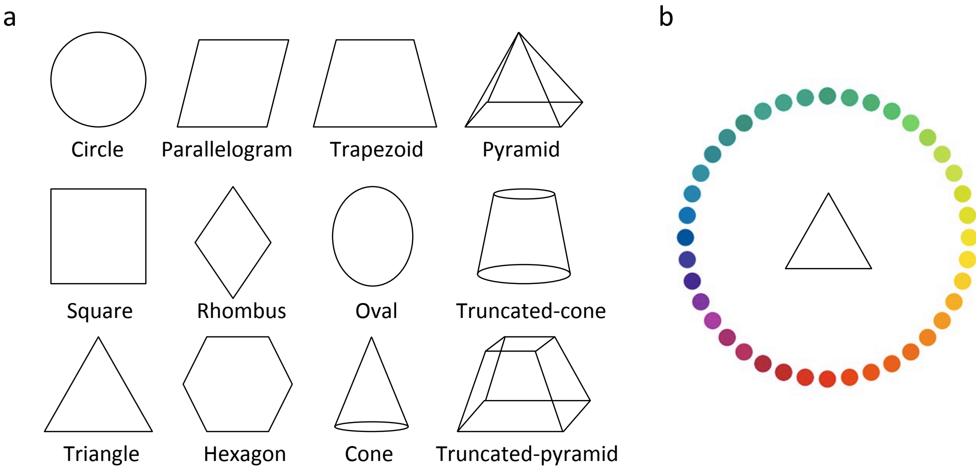


Figure 1. Stimuli of shapes and an example of the experiment display; (a) Visual stimuli of shapes in present study (0° rotation). (b) An example of stimulus display. Modified from Figure 1 of Chen et al (in press) with permission. ©American Psychological Association (APA)

2.2.2 Results and Discussion

Color-shape associations

The mean choice time for all the participants was 2,423 ms (*SD* = 1,009 ms). Participants whose mean performance time faster than 1,221ms (i.e., half of the mean choice time) were excluded, as they likely were not taking the task seriously. This resulted in the exclusion of 10 participants (7.2% of the sample).

In order to facilitate analysis and interpretation, the 40 colors were grouped into 8 categories (as in Albertazzi et al., 2013). Eight unique colors were grouped into 8 color categories with two adjacent colors on each side: 4 basic color groups—yellow (YY; No.38, 39, 40, 1, 2 in Table 1), red (RR; No.8-12), blue (BB; No.18-22), and green (GG; No.28-32)—and the other 4 transition groups—"YR" colors between yellow and red (orange; No.3-7), "RB" colors between red and blue (purple; No.13-17), "BG" colors between blue and green (blue-green; No.23-27), and "GY" colors between green and yellow (green-yellow; No.33-37).

Log-linear analysis was used to examine whether specific colors were chosen for shapes including different sizes and rotation levels, and whether the colors were consistent between the two choices. The log-linear analysis is used to examine relationships between more than two categorical variables, and includes both model building and hypothesis testing (Christensen, 1997). The model building aims to determine which variables are necessary to account for the obtained data, and results in either the simplest model or a saturated model. The simplest model assumes the independence of variables (e.g., Log(E[y]) = $\lambda_{A(i)} + \lambda_{B(j)} + \lambda_{intercept}$; Log(E[y]) is the log of the expected cell frequency for cell ij in the contingency table, $\lambda_{A(i)}$ represents the main effect for variable A, $\lambda_{B(j)}$ represents the main effect for variable B), and a saturated model includes interaction terms (e.g., Log(E[y]) =$\lambda_{A(i)} + \lambda_{B(j)} + \lambda_{A:B(i, j)} + \lambda_{intercept}$; $\lambda_{A:B(i, j)}$ shows the interaction effect for variables A and B). A final model whose Akaike's Information Criterion (AIC) value is the smallest for all combinations will be selected (Akaike, 1973). If a saturated model is determined as a best-fitting model, as follow-up test, chi-square tests at different levels on one of the variables are computed. Several studies adopted this procedure (e.g., Albertazzi et al., 2013; Woods et al., 2013). Separately from the model building, the log-linear analysis also examines whether there would be any significant interactions in all the variables even if some variables were omitted in the model building. Thus, here reported a best-fitting model and results of main effects of variables and their interactions. Chi-square tests were further conducted only when a saturated model was chosen as a final model.

As choice times among all shapes were unbalanced due to the absence of a rotation condition for the circle, I examined whether different levels of shape rotation would influence color-shape associations. A five-way log-linear analysis was conducted, shape (11) × color

(8) × size (3) × rotation (3) × choices (2), for the accumulated choice times among shapes except for circles. Importantly, results did not show any significant interactions between rotation and color (*df* = 14, χ^2 = 13.219, *p* = .509) nor between rotation, shape, and color (*df* = 140, χ^2 = 150.49, *p* = .29), indicating that the rotation effect of shapes did not significantly influence the color choices.

Next, A four-way log-linear analysis was performed, shape (12) × color (8) × size (3) × choices (2), for the accumulated choice times for all shapes except for the rotated shapes. Results showed a final best-fitting model whose Akaike's Information Criterion (AIC) value was the smallest for all combinations (Residual deviance = 343; AIC = 3,127; log-likelihood = -1467.35), and this model included shape, color, and the shape-color interaction (i.e., log (E[y]) = $\lambda_{color(i)} + \lambda_{shape(j)} + \lambda_{color:shape(i,j)} + \lambda_{intercept}$). In addition, results showed significant main effects of color (*df* = 7, χ^2 = 904.9, *p* < .001) and significant interactions between shape and color (*df* = 77, χ^2 = 918.72, *p* < .001), and size and color (*df* = 14, χ^2 = 25.16, *p* < .05). However, we did not find significant interactions between choices and color (*df* = 7, χ^2 = 6.75, *p* = .45) and choices, color, and shape (df = 77, χ^2 = 68.91, *p* = .73). These results indicated that color selections for shapes between the first and second choices were not significantly different.

As significant interaction between color and shape was observed, and the best-fitting model included the interaction between these variables, post-hoc chi-square tests was conducted for each shape, and multiple comparisons using Ryan's method (Hsu, 1996) was adopted to examine if some colors were significantly more chosen for some shapes. Results showed significant differences for all shapes (circle, χ^2 = 485.75; square, χ^2 = 59.45; triangle, χ^2 = 323.13; parallelogram, χ^2 = 77.271; rhombus, χ^2 = 174.08; hexagon, χ^2 = 40.75; trapezoid, χ^2 = 39.63; oval, χ^2 = 306.06; cone, χ^2 = 177.96; pyramid, χ^2 = 206.46; truncated cone, χ^2 = 92.52; truncated pyramid, χ^2 = 44.91; note that all degrees of freedom value = 7, and *ps* < .01). Multiple comparisons showed that some colors were more frequently associated with shapes than other colors: circle, RR (34.37%), YY (20.70%), YR (14.84%); square, n.s.; triangle, YY (33.3%); parallelogram, n.s.; rhombus, YY (24.6%); hexagon, BB (16.14%); trapezoid, BB (17.83%); oval, YY (27.86%), RR (20.18%), YR (17.31%); cone, YY (25.78%); pyramid, YY (28.38%), BB (16.14%), YR (14.84%); truncated cone, YY (19.14%), BB (19.92%); truncated pyramid, n.s. (see Table 2).

Those results showed that shapes with different perceptual characteristics led to systematic biases in color choices. Namely, some shapes were consistently associated with specific colors. For example, shapes with curved lines (e.g., circle and oval) were more frequently associated with RR (red), YR (orange), and YY (yellow); shapes with sharp apex angles (e.g., triangle, pyramid, rhombus, and cone) were more frequently associated with the color YY (yellow); some straight-line squared shapes (e.g., hexagon and trapezoid) tended to be more frequently associated with the color BB (blue).

Table 2. Contingency table (color choice frequency for shape, %)

	YY	YR	RR	RB	BB	BG	GG	GY
Circle	**20.7**	**14.84**	**34.37**	8.98	8.72	3.12	4.03	5.2
Square	13.8	8.85	11.84	13.93	19.4	10.41	14.19	7.55
Triangle	**33.33**	8.2	12.76	9.5	11.97	6.51	9.76	7.94
Hexagon	14.32	8.46	14.19	14.32	**16.14**	11.32	13.67	7.55
Trapezoid	11.58	9.89	10.28	12.76	**17.83**	14.45	14.58	8.59
Oval	**27.86**	**17.31**	**20.18**	8.2	10.28	5.33	3.9	6.9
Parallelogram	18.48	9.37	8.85	10.15	18.35	9.76	15.62	9.37
Rhombus	**24.6**	10.15	15.1	11.19	17.57	4.55	8.72	8.07
Cone	**25.78**	9.37	16.53	10.54	14.32	4.81	9.89	8.72
Pyramid	**28.38**	10.67	9.5	9.37	**16.14**	7.16	9.76	8.98
Truncated cone	**19.14**	13.02	8.98	11.19	**19.92**	8.72	11.06	7.94
Truncated pyramid	14.19	9.11	8.72	12.23	16.27	13.67	16.66	9.11
Overall	21.01	10.77	14.27	11.03	15.57	8.31	10.98	7.99

Note. Cells in bold indicate a significant association between color and shape, p < .05.

Comparison between Japanese and Italian participants

In order to compare the color-shape associations of Japanese with that of Italian from a previous study (Albertazzi, et al., 2013), a three-way log-linear analysis was performed, shape (12) × color (8) × country (2), for the accumulated choice times from the two populations. In order to be consistent with the previous study, I adopted the middle size and no rotation trials among all the shapes here. As the relative choice frequency for color groups with each shape was provided (Albertazzi, et al., 2013), the choice times from 60 Italian participants and two time sessions were calculated: choice times = choosing frequency × 60 (participants) × 2 (two sessions).

The log-linear analysis showed a best-fitting model in which the AIC value was the smallest for all combinations (Residual deviance = 713.8; AIC = 1,653; log-likelihood = -820.65), which retained shape, color, country, a shape-color interaction, and a color-country interaction, $\log(E[y]) = \lambda_{color(i)} + \lambda_{shape(j)} + \lambda_{country(h)} + \lambda_{color:shape(i,j)} + \lambda_{color:country(i,h)} + \lambda_{intercept}$. Importantly, the best-fitting model did not include the interaction between country, color, and shape, which indicates less of a country influence on color-shape associations. Although results showed significant interactions between country, color, and shape ($df = 77$, $\chi^2 = 121.70$, $p < .01$), this is likely due to the difference in sample sizes. The present study included 128 Japanese while the previous study included 60 Italian participants. In order to exclude the difference of sample size effect, the Japanese participants choice times were corrected by creating a proportion based on the two samples (2.13 [128/60 = 2.13]). A log-linear analysis on the adjusted color choices in Japanese and Italian participant was conducted. Results showed that the significant interaction between country, color, and shape was eliminated ($df = 77$, $\chi^2 = 73.81$, $p = .58$), which might suggest that the present results and those from the previous study showed a similar tendency, that Japanese and Italian participants established similar patterns of color-shape associations. Combined with the previous study with Italian participants, consistent color-shape associations were observed. For example, curved-line shapes, such as circles and ovals, are more frequently associated with "warm" colors: RR (red), YY (yellow), and YR (orange). Sharp, angular shapes, such as triangle, rhombus, cone, and pyramid are more frequently associated with the color YY (yellow). These putative associations were partially consistent with the previous researches (i.e., red-circle and yellow-triangle associations; Albertazzi et al., 2013; Dumaitrescu, 2003, 2011; Kharkhurin, 2012; Lupton & Miller, 1993). These results indicated that color-shape associations might be consistent among Japanese and Italian people, and could be independent from cultural backgrounds, word sounds, or learning experience. It is likely that color-shape associations are influenced by the semantic information of colors and shapes.

Consistency of color-shape associations

Although the color choices for certain shapes were likely consistent between the two choices, the consistency of those color-shape associations was scrutinized. A higher consistency in the color-shape association indicates a strong and stable association. Thus, the hue color distance between the first and second choices were calculated for all trials using CIELAB hue angles (Table 1). Figure 2 shows the color distances between the two choices for each shape. Some significant differences in color choice consistency in terms of shape dimension, color warmth, and the three basic shapes were observed.

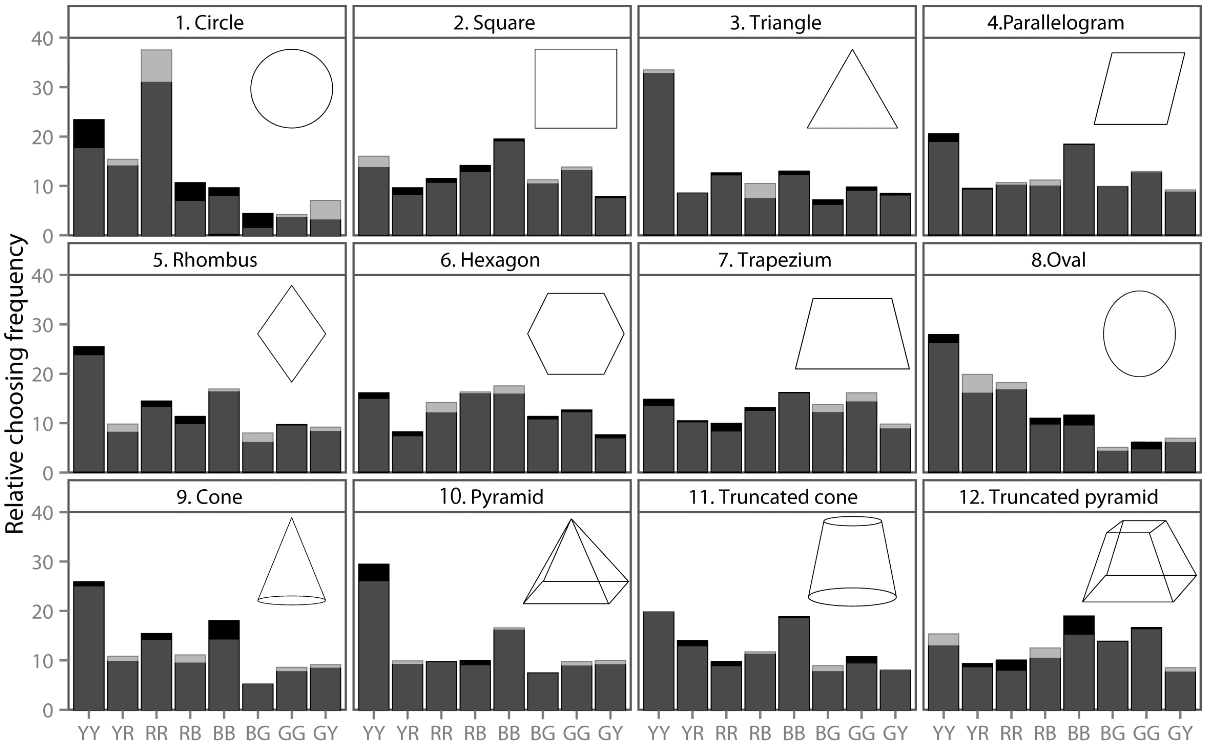


Figure 2. Choosing frequency of colors for shapes in the first and second choice. The Black bars indicate the result of the first choice and the transparent grey bars indicate the result of the second choice.

The color distances between the first and second choices in terms of shape dimension (i.e., 2D vs. 3D; Fig. 3b) showed that color-shape associations were more consistent in 2D shapes than in 3D shapes, $t(127) = 3.17$, $p < .01$. This might be because 3D shapes have volume perception, with more lines, and thereafter perceived as more complex than 2D shapes, which probably lead to uncertain and less consistent color assignment.

Results indicated that some shapes were associated with warm colors (e.g., circle and oval with red) while others were associated with cold colors (e.g., trapezoid and hexagon with blue). Color warmth seems to influence the color-shape associations (Albertazzi et al., 2013). The consistency of color-shape associations in terms of color warmth was examined. Here, color groups GY, YY, YR, and RR were regarded as warm colors and color groups RB, BB, BG, and GG were regarded as cold colors according to the dominant wavelength (Ballast, 2010). Results showed that color-shape associations with warm colors were more consistent than those with cold colors, $t(127) = 10.02$, $p < .001$ (Fig. 3c). Thus, color-shape associations with warm colors for shapes seem to be more stable than those with cold colors.

Following Kandinsky's correspondence theory on the basic three shapes, past studies on color-shape associations have mainly discussed the color assignment for the three basic shapes including circle, square and triangle. Here, the consistencies in color assignment for the three basic shapes were examined. A one-way ANOVA revealed a significant difference on color distance between the three shapes, $F(2, 254) = 23.26$, $p < .001$; post-hoc Shaffer's method: circle < triangle < square, $p < .01$. Thus, choices of RRs for a circle were the most consistent, triangle-yellows were the second consistent, and colors for a square were the least consistent, among RB, BB, BG, and GG (Fig. 3d). Specifically, circle-red association was the strongest association among all the shapes (choice frequency: 34.37%), and triangle-yellow showed the second strongest association (33.33%), while a square exhibited the weakest color-shape associations (BB: 19.4%). This was the first to examine the differences among the three basic shapes in terms of their color-shape associations and the consistency of those associations. One possible explanation could be that curved or non-curved visual features are the key visual primers that mediate rapid impression formation (Bar & Neta, 2006). The curved-line shapes are associated with positive semantic information such as warmth, compared with straight-line shapes (Liu, 1997; Liu & Kennedy, 1993; Oyama & Haga, 1963), which might contribute to the strong and stable associations observed for the curved shapes. Another explanation could be that Japanese participants associated a circle with red because of salient cultural influences: the Japanese flag has a red circle in the center of a white background, which might lead to a strong circle-red association. Collectively, the consistency in color assignments for shapes between the two choices revealed that semantic information evoked by physical visual properties likely affected the strength of these observed associations.

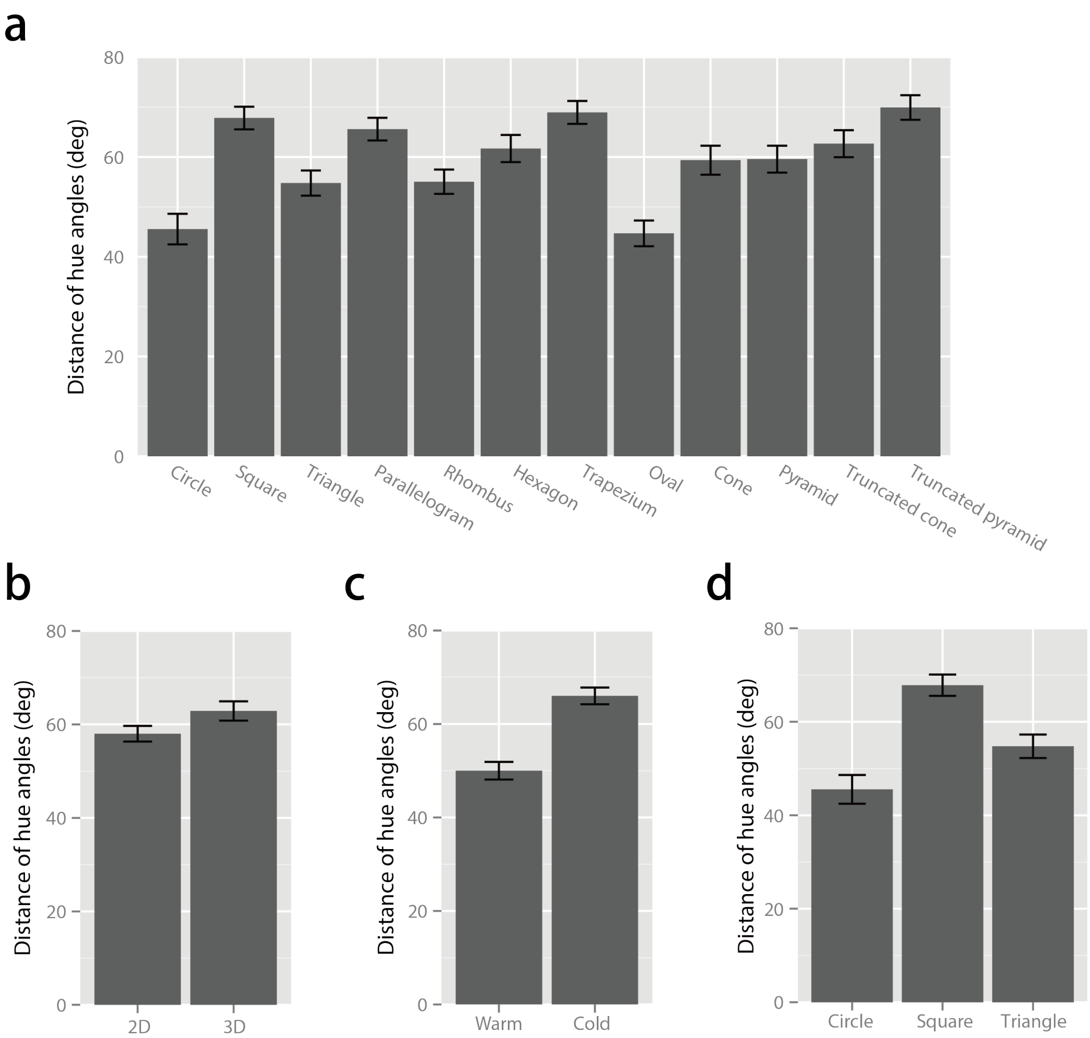


Figure 3. The absolute color distance between the two choices. (a) Color distance for all shapes. (b) Color distance for 2D and 3D shapes. (c) Color distance for color warmth. (d) Color distance for the basic shapes. Means are calculated for participants. Error bars represent the standard errors of the mean.

Correspondence analysis

For better understanding of the associations between shapes and colors, I further conducted a correspondence analysis (CA) on the contingency table of choosing times, shape (12) × color (8), using a statistical software (XLSTAT, Addinsoft, NY, USA). Correspondence analysis is a statistical method to examine the associations between the levels of a contingency table and provide a summarized set of data in two-dimensional graphical form (Greenacre, 2007). The CA configuration represents the similarity of color-shape assignment profiles. Shapes and colors that are located closely to each other have a similar pattern of assignment profiles.

The result of CA analysis revealed that the first two dimensions (i.e., components F1 and F2) accounted for 89.30% of the total variance, which indicated a strong and good fit among the CA dimensions to interpret the color-shape associations. In particular, F1 explains a large portion of total variance (67.48%). Figure 4 shows the projection of the CA dimensions (Fig. 4 is modified from Figure 3 of Chen et al (In press) with permission). In the right area, circle is located close to the color RR. The oval, rhombus, cone, and truncated cone are also located nearest to colors YY, YR, and GY. In the bottom area, the triangle and pyramid are located close to color YY. In the left area, the hexagon, truncated pyramid, trapezoid, and square are located close to colors BG, GG, RB, and BB. As the first two dimensions of the CA (i.e., factor F1 and F2) could explain most of variation in color-shape associations, Albertazzi et al. (2013) suggested that the F1 and F2 factors could be interpreted by the "warmth" and "lightness" of the colors. It is possible that, in our results, the horizontal axis (F1 factor) could also be explained by "warmth" and the vertical axis (F2 factor) by "lightness." However, means for interpreting the F1 and F2 factors remain open to debate. In the next experiment, the possible explanations for the F1 and F2 factors in terms of interpreting color-shape associations were explored.

In Experiment 1, the results showed tendencies in which certain colors were more frequently associated with certain shapes. By comparison with the previous studies (Albertazzi et al., 2013), results suggested that color-shape associations are likely independent of cultural influences, and might stem from some semantic information connections of colors and shapes. Provided that common semantic information among colors or shapes (e.g., warmth or lightness) would be the major force behind color-shape associations, the present experiment could be seen as a replication of the previous study of interest (i.e., Albertazzi et al., 2013). In the Experiment 2, the interpretations of color-shape associations were addressed through a regression analysis with semantic information among colors and shapes based on dimensions obtained by the CA.

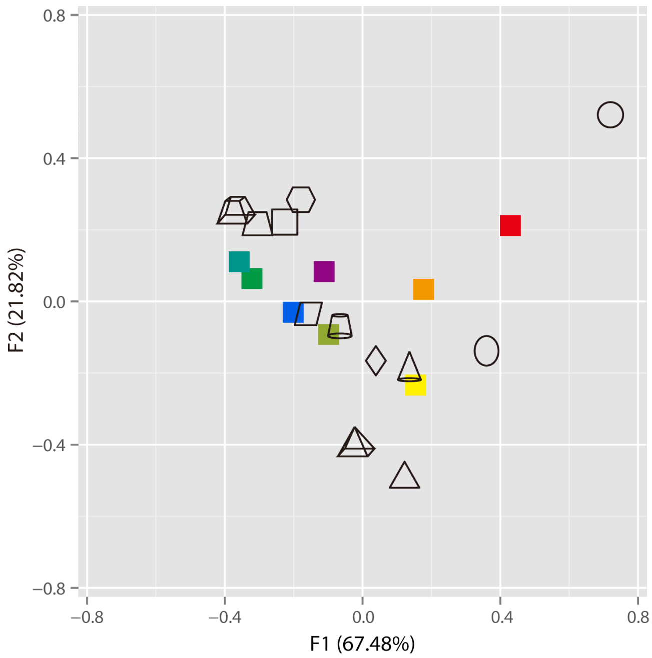


Figure 4. Projection of colors and shapes in CA dimensions. Modified from Figure 3 of Chen et al. (in press) with permission. ©APA

2.3 Experiment 2: Semantic ratings for colors and shapes

Taken together with Albertazzi et al. (2013), the congruent semantic information between colors and shapes likely accounts for color-shape associations. To confirm this further, the possible correlations between semantic information and the two CA dimensions were examined (i.e., F1 and F2 factor).

In a preliminary experiment, two graphs of the CA results from Experiment 1 (i.e., color projection and shape projection respectively) were shown to a new group of 25 Japanese participants, with asking them to report the most appropriate adjective to explain the horizontal and vertical axes (i.e., F1 and F2 factor). Results showed that, for the color plot, “warm/cold” (48%) was reported most frequently to describe the horizontal axis (F1 factor) and “heavy/light” (48%) for the vertical axis (F2 factor). For the shape plot, the most frequently reported adjective for the horizontal axis (F1 factor) was “round/sharp” (70%), but consistent adjectives were not found for the vertical axis (F2 factor).

In Experiment 2, newly recruited participants were asked to rate how much each color and shape was “warm/cold,” “heavy/light,” and “round/sharp” on a 7-point Likert scale. The aim of this experiment was to investigate whether these adjective ratings correlated with the CA dimensions as a way to interpret the observed color-shape associations.

2.3.1 Methods

Participants

Twenty-two Japanese college students participated in the experiment (10 females, mean age = 21.2, *SD* = 1.8). All had normal or corrected to normal visual acuity and normal color vision. None had participated in the previous experiments.

Stimuli and procedure

The visual stimuli consisted of 40 hue color patches and 102 geometric shapes used in Experiment 1, and the experimental environment was the same as in Experiment 1. Participants were seated in front of the computer monitor and instructed to rate each color and shape stimulus appeared at the center of the screen on a white background (90 cd/m^2), with a 7-point Likert scale, from 1 (*cold/light/sharp*) to 7 (*warm/heavy/round*). Colors and shapes were rated in two separate sessions. Participants responded with using a computer mouse on a numeric square labeled from 1 to 7. The experiment lasted about 15 minutes.

2.3.2 Results and Discussion

Adjective ratings of colors and shapes

Ratings were standardized, and Figure 5 shows the mean standardized ratings of the three pairs of adjectives for each color and shape. One-way ANOVAs on the mean standardized ratings for the semantic adjectives (warm/heavy/round) were conducted separately. We observed the significant main effects of both color (warmth: $F(7, 144) = 63.55$, $p < .01$; heaviness: $F(7, 144) = 47.09$, $p < .01$; roundness: $F(7, 144) = 2.33$, $p < .05$) and shape (warmth: $F(11, 231) = 28.83$, $p < .01$; heaviness: $F(11, 231) = 27.79$, $p < .01$; roundness: $F(11, 231) = 145.98$, $p < .01$). Post-hoc multiple comparisons showed that certain colors and shapes were perceived as significantly different from others in terms of the three adjective values. For the rating of warmth, the colors YR, RR, and YY were rated warmer than the colors RB, BB, BG, GG, and GY. Curved-line shapes, such as circle, oval, and truncated cone, were warmer than other shapes. For the rating of heaviness, the colors RR, RB, and YR were rated heavier than the colors GY, GG, YY, and BG. The 3D shapes of truncated pyramid, pyramid, truncated cone, and cone were heavier than other 2D shapes. For the rating of roundness, the color GY was more round than the color RB, and circle, oval, and truncated oval were more round than other shapes (Bonferroni corrections, all *p*s < .05).

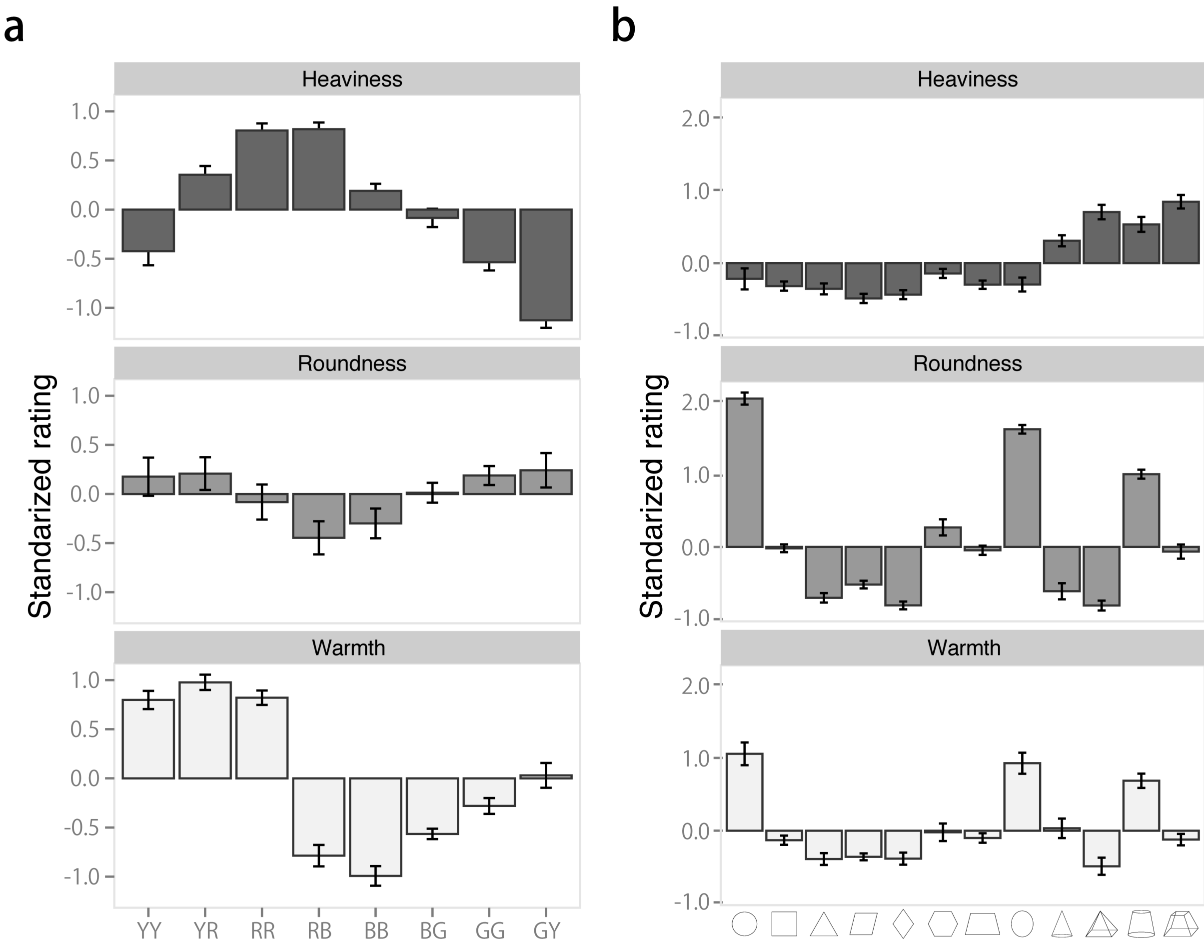


Figure 5. Mean standardized ratings of adjective pairs for colors and shapes. Means are calculated for trials of 22 participants. Error bars represent the standard errors of the mean. Modified from Figure 4 of Chen et al. (in press) with permission. ©APA

Correlation analysis with F1/F2 factors and adjective words

Correlation analysis with the three pairs of adjective ratings and the F1 and F2 factors of the CA dimensions showed that the warm-cold ratings exhibited significant correlations with the F1 factor for both color and shape (color contribution to the F1 factor — color warmth: $r(6) = 0.81$, $p < .01$; shape contribution to the F1 factor — shape warmth: $r(10) = 0.65$, $p < .05$; Fig. 6). The other adjective pairs (heavy/light, round/sharp) did not show significant correlations with color and shape contributions to the F1 nor F2 factors. The round/sharp ratings showed significant correlations with the shape contribution to both the F1 and F2 factors (shape contribution to the F1 factor — shape roundness: $r(10) = 0.57$, $p < .05$, shape contribution to the F2 factor — shape roundness: $r(10) = 0.56$, $p < .05$), but the roundness rating of color did not reveal any significant correlations with color contributions to the F1 nor F2 factors (color contribution to the F1 factor — color roundness: $r(6) = 0.08$, $p = .85$; color contribution to the F2 factor — color roundness: $r(6) = -0.37$, $p = .36$). The heavy/light ratings significantly correlated with color contribution to the F2 factor (color contribution to the F2 factor — color heaviness: $r(6) = 0.62$, $p < .05$), but did not show any significant correlations with shape heaviness rating (shape contribution to the F2 factor — shape heaviness: $r(10) = -0.11$, $p = .73$). Therefore, the horizontal axis (F1 factor) of the CA dimensions could be interpreted as the warmth of both colors and shapes, while the vertical axis (F2 factor) could be explained by the roundness of the shape and heaviness of the color. There are likely no single and consistent pairs of adjectives that could describe colors and shapes for the F2 factor. In short, the F1 axis might be predicted from the congruity of warmth perception for both color and shape, but the F2 axis was not well explained by the combination of the roundness of the shape and the heaviness of the color.

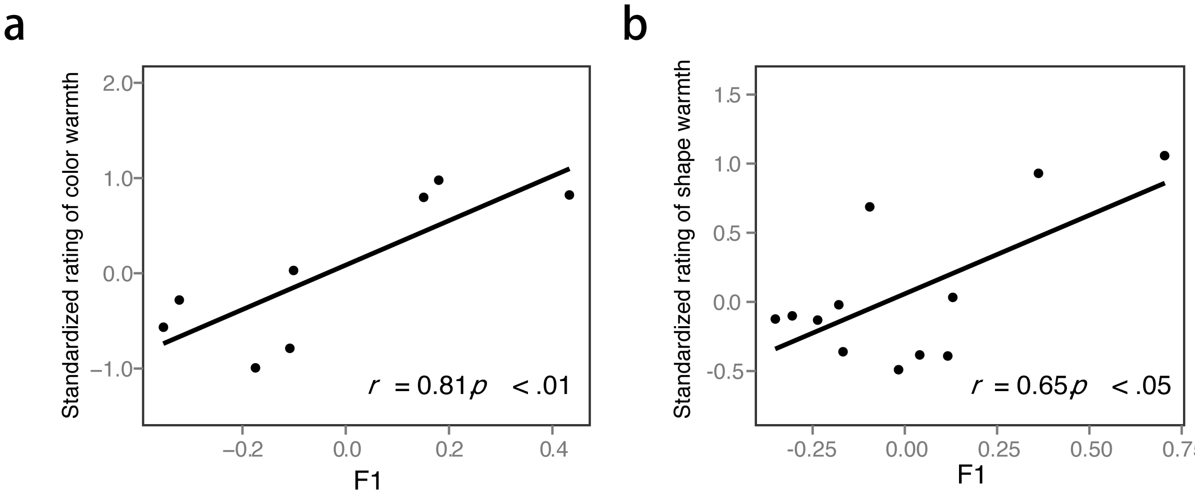


Figure 6. Correlation between F1 and the warmth rating. (a) Standardized rating of color warmth as a function of color scores of F1. (b) Standardized rating of shape warmth as a function of shape scores of F1. Modified from Figure 5 of Chen et al. (in press) with permission. ©APA

From the CA dimensions (Fig. 4), for the horizontal axis (F1 factor), warm colors (e.g., RR, YR, and YY) were located in the positive direction, close to the location of warm shapes (e.g., circle, oval, cone). In contrast, cold colors (e.g., BB, BG, and GG) were located in the negative direction and were associated with cold shapes (e.g., square, hexagon, and trapezoid). On the vertical axis (F2 factor), round shapes (e.g., circle, hexagon) and sharp shapes (e.g., triangle, pyramid) were located in the opposite direction and paired with heavy colors (e.g., RR, RB) and light colors (e.g., YY, GY), respectively. In other words, round shapes tend to be associated with heavy colors, and sharp shapes tend to be matched with light colors. These results partially supported Albertazzi et al. (2013) in which color "warmth" accounted for the F1 factor, and "lightness" explained the F2 factor. Although, the "light/dark" ratings of colors and shapes were also tested in the preliminary experiment, any congruent correlations with color and shape contributions to the F1 or F2 factors were observed. As the horizontal axis (F1 factor) accounted for most of the CA dimensions (67.48%), which could explain most of the color-shape associations, the common semantic information such as "warmth" perception of colors and shapes might lead to these color-shape associations.

Correlation analysis of choice frequency with adjective ratings

Results from the CA dimensions suggested that warmth of color and shape might explain most of the observed color-shape associations. To address this possibility, the data from Experiments 1 and 2 were combined and correlation analysis was performed on the choice frequency of colors for each shape (Experiment 1) and the ratings of adjectives (i.e., warmth/heaviness/roundness) for each shape (Experiment 2). Results showed that the choice frequencies of warm colors YR and RR were positively correlated with warmth ratings for shapes, while choice frequencies of cold colors BB, GG, and GY were negatively correlated with the warmth ratings for shapes, and specific tendencies were not observed for other adjectives (see Table 3). These results indicated that warm colors were significantly associated with warm shapes and further supported our findings.

Table 3. Correlations between colors and adjectives

	YY	YR	RR	RB	BB	BG	GG	GY
Warmth	-0.061	**0.896**	**0.667**	-0.116	**-0.575**	-0.486	**-0.596**	**-0.814**
Roundness	-0.187	**0.836**	**0.666**	-0.009	**-0.578**	-0.354	-0.492	**-0.874**
Heaviness	-0.069	-0.027	-0.269	-0.061	0.27	0.198	0.178	0.24

Note. Cells in bold indicate significant correlations, $p < .05$

Correlation analysis between adjective ratings for colors and shapes

In order to further confirm the hypothesis, a correlation analysis on the ratings of warmth for colors and shapes was performed. Results showed significant correlations between the warmth ratings for some colors and shapes ($r(20) > 0.35$, $p < .05$; Table 4). For example, the warmth ratings for the circle and square were significantly correlated with those for RR and BB, respectively; people who rated the circle (square) as a warm (not-warm) shape also rated the RR (BB) as warm (not-warm) color. Therefore, the correlations between warmth ratings for colors and those for shapes also support the hypothesis.

Table 4. Correlations between warmth ratings of colors and shapes

	YY	YR	RR	RB	BB	BG	GG	GY
Circle	0.18	0.33	**0.44**	0.22	0.06	0.28	0.25	0.17
Square	0.17	0.35	0.14	**0.41**	**0.39**	0.25	-0.07	0.01
Triangle	0.23	0.35	-0.14	0.08	0.19	0.02	-0.11	0.08
Hexagon	**0.46**	**0.36**	0.03	0.3	0.13	0.16	-0.1	0.22
Trapezoid	0.13	0.18	-0.03	0.34	**0.42**	**0.39**	0.06	0.12
Oval	0.06	0.18	**0.35**	0.2	0.09	0.27	0.32	0.13
Parallelogram	**0.38**	0.32	-0.01	**0.39**	0.32	**0.49**	0.31	0.32
Rhombus	0.32	0.22	-0.16	0.19	0.31	**0.4**	0.33	**0.36**
Cone	0.3	0.25	-0.03	0.17	0.22	**0.41**	**0.5**	0.18
Pyramid	0.19	0.2	-0.11	0.1	0.22	-0.03	-0.1	-0.01
Truncated cone	0.24	0.34	0.23	0.26	0.27	**0.43**	**0.47**	0.15
Truncated pyramid	0.05	-0.01	-0.15	**0.38**	**0.48**	0.31	0.05	-0.07

Note. Cells in bold indicate significant correlations, $p < .05$

2.4 Discussion

This chapter investigated color-shape associations in Japanese participants. Results showed that Japanese participants established systematic associations between colors and shapes, in consistent with the findings for Italian participants (Albertazzi et al., 2013). The common semantic information of "warmth" to colors and shapes suggested to interpret for a large portion of observed color-shape associations. Besides, certain color-shape associations were more consistent and stable, such as the circle-red link.

Color-shape associations among Japanese and Italian participants

In comparison with Albertazzi et al. (2013) using Italian participants, results showed consistent color-shape associations, which suggested universal tendencies in color-shape associations. For example, round shapes (e.g., circle, oval) were associated with warm colors (e.g., YR and RR); sharp angular shapes (e.g., triangle, rhombus, pyramid, and cone) tended to associate with color YY; squared shapes (e.g., square and parallelogram) were likely related to cold colors (e.g., BB). Hence, color-shape associations were consistent across culture, language, and word sounds to some extent. For example, the phonetics for the words "circle," "triangle," and "square" are remarkably different between the Italian and Japanese ("cerchio [/ˈtʃerkjo/]," "triade [/ˈtriade/]," "quadrato [/kwaˈdrato/]" in Italian, and "maru [/'mɑ:ru/]," "sankaku [/sa:ˈka:ku:/]," "shikaku [/ʃiˈka:ku:/]" in Japanese, respectively). Moreover, the phonetics for colors are different (e.g., the color red, blue, and yellow are pronounced as "rosso [/'ro:sso/]", "blu [/blu/]", and "giallo [/'ʤaːllo/]" in Italian, and "aka [/'ɑ:ka/]", "ao [/'ɑ:o/]", and "ki [/'ki:/]" in Japanese). It seems that sounds of the circle and red, the triangle and yellow, the square and blue are different from each other between Japanese and Italian language. Then, I assume that the sounds of words may not account for the color-shape associations. It is more reasonable that color-shape associations are likely determined by some semantic information common in colors and shapes.

Semantic associations between colors and shapes

Previous studies have suggested that visual properties of colors and shapes convey some semantic information, and the semantic information could be congruent and shared to some extent (Ballast, 2010; Liu & Kennedy, 1993; Nakano, 1972; Oyama, 2003; Ou, et al., 2004). For example, colors can be described in warm or cold, and dark or light, according to the dominant wavelength and lightness of colors (e.g., reds are warm, blues are cold, and yellows are bright). Similarly, shapes can be perceived as round or sharp, and hard or soft. Liu and Kennedy (1993) reported that round shapes convey warm and soft impressions, while squared shapes convey cold and hard impressions. Importantly, it is also possible to imagine "hard or soft" colors and "warm or cold" shapes, which indicate that semantic information common to colors and shapes might lead to the associations. Results of Experiment 2 showed that semantic information of "warm/cold" common to colors and shapes explained a majority of the color-shape associations. Warm colors (e.g., RR and YR) tended to be associated with warm shapes (e.g., circle and oval), and cold colors (e.g., RB, BB, and BG) tended to be associated with cold shapes (e.g., hexagon and trapezoid, etc.). In addition, the round shapes being associated with heavy colors, and sharp shapes being associated with light colors, which might explain some of the variance in color-shape associations. Collectively, common semantic information to colors and shapes contributed to the color-shape associations, particularly with the perception of "warmth."

Prototype effect

The strong associations in yellow-triangle and red-circle might stem from daily life experience (e.g., signs in the transportation system, golden pyramids, and a red sun). Jacobsen and Wolsdorff (2007) also suggested the assignments of red to triangle and yellow to circle were influenced by everyday knowledge. The observed red-triangle in their study might resemble a traffic yield sign, and the yellow-circle might resemble the sun (Jacobsen, 2002; Jacobsen & Wolsdorff, 2007). It is possible that people unconsciously match colors to shapes based on the learning knowledge about familiar objects. In Albertazzi et al. (2013), the authors explicitly instructed participants not to use typical colored objects as a reference for judgments, whereas in the present study participants were asked to intuitively choose the best-matched color for a shape. Despite the differences in procedure, results between the two studies are remarkably similar and suggest two possibilities. One is that certain color-shape associations are consistent across cultures and might be invariant to everyday knowledge. Another possibility is that color-shape associations might be influenced by everyday knowledge even if participants are asked to avoid imagining typical objects. Differences in everyday knowledge between Italian and Japanese individuals may affect the results, and everyday experience with visual color and shape environments likely differs between the two cultures. However, certain color-shape associations were still consistent across the two cultures and seemed to be invariant to one's prior knowledge.

Importantly, the present study separately presented colors and shapes in the experiment and did not show any hue-colored shapes. Indeed, colored shapes carry semantic information different from when colors and shapes are independently shown. For example, Sommer et al. (2004) examined the semantic connotation of shapes presented in different hues, and observed that colors have more of an influence than shapes on the connotation of activity and evaluation, and colors can potentiate shape values by adding new effects. Thus, the lack of colored shapes might lead to weaker prototype effects or different effects from the prototype effects. This may need future studies on semantic information related to the integrated colors and shapes.

Summary

In this chapter, I examined the general color-shape associations in Japanese people with an explicit matching task. I observed that Japanese people have specific color-shape associations, which were consistent with those of Italian samples. Furthermore, these color-shape associations could be interpreted by semantic information common to colors and shapes. Specifically, the "warmth" of colors and shapes might explain a large portion of the observed associations.

The Experiment 1 used an explicit matching task to directly investigate people's color-shape associations, which allows participants to think a relatively long time. This experimental paradigm might lead to findings influenced by the prototype effect. That is, participants might unconsciously refer to the colored objects encountered in the living environment. Besides, if color-shape associations were generally encoded, they would be measured in the indirect test, not only in those using explicit response. In another word, people may not show some color-shape assignment when directly inquired, but should indicate the preference if tested indirectly.

In the Chapter 3, an indirect behavioral experimental method (i.e., implicit association test) was used to test the color-shape associations, both with Kandinsky's correspondence theory and the findings with Japanese people's color-shape associations.

3. Color-shape associations by the implicit association test (IAT)

3.1 Introduction

Kandinsky's correspondence theory of color-shape associations posits the linkages red-circle, blue-square, and yellow-triangle. These links have been studied using direct and indirect experimental methods by researchers. However, most studies have failed to provide support for the correspondence theory. Experiment 1 suggested the Japanese color-shape associations consist of circle-red, square-blue, and triangle-yellow. Both Experiment 1 and Kandinsky's study used direct matching tasks, which may rely on introspective judgment. If color-shape associations were encoded, they should be proved using the indirect behavioral experimental method, such as the implicit association test.

Some studies have adopted indirect behavioral methods to investigate color-shape associations. However, those studies have failed to provide evidence for Kandinsky's color-shape associations (Kharkhruin, 2012; Makin & Wuerger, 2013). For example, Kharkhurin (2012) conducted two experiments using an implicit priming technique and a recognition test. He first tested whether a color-priming stimulus would influence the discrimination of a subsequent shape stimulus, with the hypothesis that response times (RTs) would be faster if the priming color was associated with the shape. Then, in the second experiment, he measured RTs in a discrimination task using a shape filled with one of various colors, hypothesizing that discrimination times would be faster for shapes filled with the associated color. However, both experiments failed to reveal any acceleration of RTs in the congruent conditions that would be congruent according to Kandinsky's correspondence theory. Makin and Wuerger (2013) used implicit association tests (IATs) to examine Kandinsky's correspondences in British participants. They found only a marginal effect in one combination among the three combinations they tested.

Taken together, previous studies have shown little support for Kandinsky's color-shape associations, regardless of whether direct or indirect experimental methods were used (Albertazzi, et al., 2013; Jacobson, 2002; Jacobsen & Wolsdorff, 2007; Lupton & Miller, 1991; Dumitrescu, 2011; Kharkhruin, 2012; Holmes & Zanker, 2013; Makin & Wuerger, 2013). Possible reasons might be that Kandinsky's correspondence theory is not universal or it is simply incorrect. Previous studies using explicit matching tasks have shown that there exist other color-shape associations, such as the associations observed in the present Experiment 1 (i.e., circle-red, triangle-yellow, and square-blue). Then, one may ask is: Is it possible to demonstrate color-shape associations with use of indirect behavioral measures? It may be that these associations are constructed only through subjective introspections, and may not exist when measured using indirect behavioral performance that requires quick judgments. However, the other possibility is that there are other patterns of color-shape associations (e.g., Japanese color-shape associations in Experiment 1), which have not being tested through indirect behavioral measures so far, but might be proved through the indirect behavioral measures.

In this chapter, I examined whether either of the two forms of color-shape associations reported in direct matching tasks in previous studies could be replicated using an indirect behavioral method. The two associations were those from Kandinsky's correspondence theory (i.e., circle-blue, triangle-yellow, and square-red) and the aforementioned Japanese color-shape associations (i.e., circle-red, triangle-yellow, and square-blue in Experiment 1).

For this, I adopted the implicit association test (IAT), which is known to be a useful tool for revealing unconscious associations between stimulus dimensions (Greenwald, McGhee,

& Schwartz, 1998; Nosek, Greenwald, & Banaji, 2007). In the IAT, participants must classify four stimulus categories by pressing two different response keys. Participants were instructed to press one key rapidly and accurately for one stimulus from one pair of visual stimuli and to press the other key for one stimulus from the other pair of visual stimuli. If the two stimuli assigned to the same key are associated (congruent condition), the RTs should theoretically be shorter than in the condition in which two stimuli assigned to the same key that are unassociated (incongruent conditions). Hence, the IAT reveals associations at the level of response selection.

This paradigm has been widely used to assess the strength of associations between different stimulus dimensions (Ho et al., 2014; Parise & Spence, 2012; Gattol, Saaksjarvi, & Carbon, 2011). Multiple IAT tasks were used here, to explore the associations between the three colors and three shapes noted in Kandinsky's correspondence theory (Makin & Wuerger, 2013; Gattol, Saaksjarvi, & Carbon, 2011).

In Experiment 3, I replicated the study of Makin and Wuerger (2013), to examine whether Kandinsky's correspondence theory could be observed in Japanese participants. In Experiment 4, I explored Japanese people's color-shape associations, reflecting the findings of Experiment 1.

3.2 Experiment 3: Kandinsky's color-shape associations by IAT

3.2.1 Method

Participants

Thirty-eight Japanese college students took part (24 males, mean age = 21.5, *SD* = 1.5). All participants had normal or corrected-to-normal visual acuity and normal motor functions, and were naïve to the purpose of this study.

Apparatus and stimuli

Stimuli were presented at 60cm on a 1280 × 1024 pixel CRT monitor, with a refresh rate of 60 Hz. E-Prime 2.0 software (Psychology Software Tools, Inc.) was used to present the stimuli and collect the data. The three shape stimuli were all white line drawings (with a width of 26mm, 0.03° visual angle) on a black background (8 cd/m^2). The circle was 4.8° in diameter, the square was 4.8° (in height) × 4.8° (in width), and the triangle was 4.8° (in height) × 5.8° (in width). The three shape stimuli were always presented in the upward orientation. Color patches were ~9.5° wide (Gaussian-modulated). The colored Gaussian patches were measured using PR-655 (Photo Research, Chatsworth, CA, USA) and each color was consecutively measured 10 times and averaged. The color information was described in terms of (L*, a*, b*): yellow (46.44, -2.57, 53.73), red (20.99, 37.82, 27.66), blue (27.79, -14.58, -15.12). Example stimuli are shown in Figure 7.

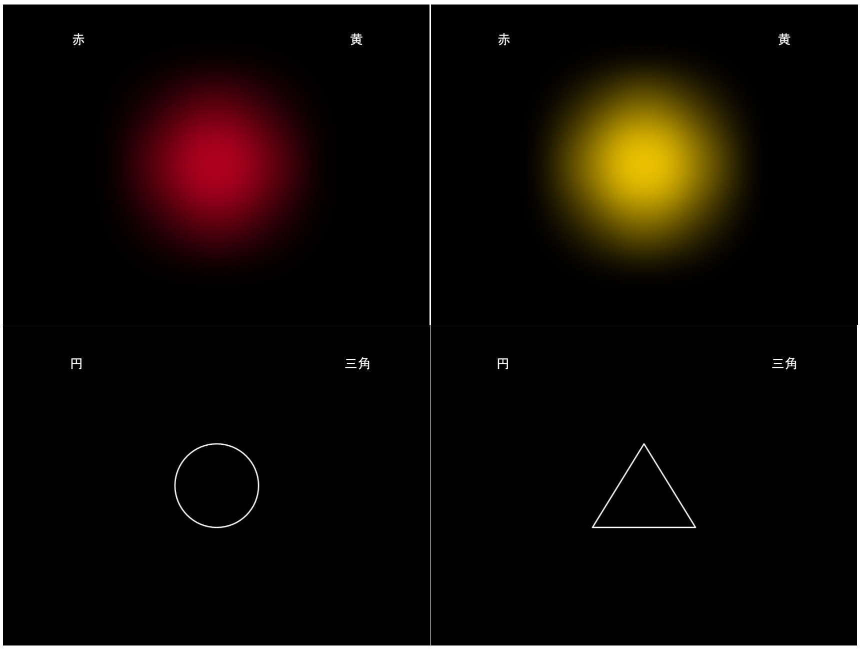


Figure 7. Example stimuli used in the Experiment 3 and 4; the words of shapes or colors appeared on the left and right sides of the screen. For example, "赤" (red), "黄" (yellow), "円" (circle), and "三角" (triangle) were used as cue words to remind participants of the key press. Modified from Figure 1 of Chen, Tanaka, and Watanabe (in press). Copyright by the authors under a Creative Commons license. Reprinted with permission.

Procedure

The experiment was carried out in a laboratory with dimmed lighting conditions (1 lux on the wall). The structure of the IAT was based on the study conducted by Makin and Wuerger (2013). The experiment paradigm was composed of three IAT tasks, each consisting of 8 blocks (Table 5 and 6). During the task, participants were asked to discriminate visual stimulus of color or shape by pressing two keys (i.e., left key "z" and right key "m") on the keyboard using the two index fingers. In the first block (Block 1), participants were trained to discriminate a shape stimulus by pressing a key (for example, the left key for circle and the right key for square, in IAT 1). In the second block (Block 2), participants were trained to discriminate a color stimulus (e.g., the left key for blue, the right key for red) by pressing a key. In the third and fourth blocks (Blocks 3 and 4), color and shape discriminations were combined, and responses were mapped according to Kandinsky's color-shape associations (e.g., the left key for circle or blue, the right key for square or red; congruent blocks). In the following two training blocks (Blocks 5 and 6), participants were instructed to learn a shape-key mapping opposite to that of the previous blocks (e.g., left key for square, right key for circle). In the last two blocks (Blocks 7 and 8), the response mapping was the opposite of Kandinsky's color-shape associations (e.g., the left key for square or blue, the right key for circle or red; incongruent blocks).

Table 5. Sequence of blocks and response mappings (example from IAT 1)

Block	Trials	Condition	Left key response	Right key response
1	20	Training 1	Circle	Square
2	20	Training 2	Blue	Red
3	20	Congruent 1	Circle or blue	Square or red
4	40	Congruent 2	Circle or blue	Square or red
5	20	Training 3	Square	Circle
6	20	Training 4	Square	Circle
7	20	Incongruent 1	Square or blue	Circle or red
8	40	Incongruent 2	Square or blue	Circle or red

In each block, the stimuli were presented in a novel random order for each participant. Cue words shown on the top two sides of the screen were used to remind participants which side of key should be used to report their answers. For example, in the first training block of IAT 1, the words “円” (circle) and “四角” (square) appeared on the top left and top right sides of the screen according to the response mapping. When participants pressed the wrong button, the word “Error” appeared centrally in red, and a beep sounded at the same time. Before each block, participants were appropriately informed of the task, stimuli, response mapping, and cue words. For instance, the instruction for block 1 in IAT 1 was as follows. “You are going to take part in a test measures your response time in discriminating visual stimulus for colors and shapes. In this block, when you see a circle (○), please press key “z” with your left index finger. When you see a square (□), please press key “m” with your right index finger. The cue words of “円” (circle) and “四角” (square) will be appeared at the top left or right sides of the screen to remind you which side of key to press. Please press the key as accurately and fast as possible. When you press the wrong key, a red word “ERROR” will appear and a beep will sound.” For another example as in the block 3, the main instruction would be changed into “when you see a circle (○) or color red, please press key “z” with your left index finger; when you see a square (□) or color blue, please press key “m” with your right index finger. The cue words of “円/赤” (circle/red) and “四角/青” (square/blue) will be appeared at the top left or right side of the screen to remind you which side of key to press.”

The order of the congruent and incongruent blocks was counterbalanced across participants; half of the participants were presented the congruent blocks first, half of the participants were presented the incongruent blocks first. Each participant completed three types of IAT tasks (response mappings are shown in Table 6). The order of the three IAT tasks was also counterbalanced across participants. Each IAT task took about 7 minutes, and participants rested 3 minutes between tasks. The whole experiment took about 30 minutes. The RTs and the number of error trials were collected for data analysis.

Table 6. The response mappings in the IATs

	Blocks	IAT 1		IAT 2		IAT 3	
		Left key	Right key	Left key	Right key	Left key	Right key
Experiment 3	Congruent blocks	Circle Blue	Square Red	Circle Blue	Triangle Yellow	Square Red	Triangle Yellow
	Incongruent blocks	Square Blue	Circle Red	Triangle Blue	Circle Yellow	Triangle Red	Square Yellow
Experiment 4	Congruent blocks	Circle Red	Square Blue	Circle Red	Triangle Yellow	Square Blue	Triangle Yellow
	Incongruent blocks	Square Red	Circle Blue	Triangle Red	Circle Yellow	Triangle Blue	Square Yellow

At the end of the experiment, participants were instructed to complete a printed questionnaire. On the questionnaire, three shapes (i.e., circle, square, and triangle) and three colors (i.e., red, blue, and yellow) were presented in two rows, with the locations counterbalanced across participants. Participants were instructed to intuitively connect the matched colors and shapes by drawing three lines, resulting in no overlapped six types of color-shape associations (e.g., circle-red, square-blue, triangle-yellow; Table 7).

Analysis

D score measure which was widely used in the IAT studies (Greenwald, Nosek, & Banaji, 2003; Nosek, Greenwald, & Banaji, 2007) was used to reveal the color-shape associations. I computed the D score of every IAT task for each participant, with reference to the study of Makin and Wuerger (2013). The step-by-step procedure for computing D scores was as follows:

1) Include trials from block 3, 4, 7, 8 in analysis.

2) Compute mean RT and standard deviation for each individual in each IAT and each congruent and incongruent condition separately.

3) Compute boundary values by adding or subtracting 2 SDs to the mean RT.

4) Include the trials [mean – 2 SD, mean + 2 SD].

5) Compute the mean RTs from block 3, 4, 7, 8.

6) Compute one pooled SD for trials in blocks 3 and 7 as $SD_{(3,7)}$, another one for blocks 4 and 8 as $SD_{(4,8)}$.

7) Compute two difference RTs in block 3 and 7 (RT 7 – RT 3) and block 4 and 8 (RT 8 – RT 4).

8) Divide each difference of RTs by its associated pooled SD from step 6, producing two D scores (e.g., $D\ score_{(3,7)} = (RT\ 7 - RT\ 3) / SD_{(3,7)}$).

9) Compute the average of two D scores (i.e., $D\ score_{(3,7)}$ and $D\ score_{(4,8)}$ in step 8), generate a final D score for each participant in each IAT.

This procedure was repeated for the three IAT tasks; therefore, each participant had three D scores for the three IATs. The D score represents the difference between the means of congruent and incongruent blocks, as a function of the standard deviation of the distribution. For participants who did congruent block first, a positive value indicates support for the proposed hypothesis, and a negative value indicates that the participant showed the opposite associations to the hypothesis.

3.2.2 Results and Discussion

Error trials (3.6%) and trials with RTs longer than 2,000 ms (0.4%) were also excluded from data analysis.

D scores

One-sample *t*-tests with Bonferroni correction (as there were six tests, the adjusted *p* value was derived from *p* value of each *t*-test multiplied by six, and then compared with the significant level of 0.05) were performed to compare D scores to zero (Fig. 8a). In IAT 1, D scores were distributed in the left (i.e., unexpected) direction (IAT 1: $t(37) = 3.42$, adjusted $p < .01$; mean D score = -0.26). This result indicates an association pattern opposite to that of Kandinsky's color-shape associations; our participants associated circle with red and square with blue. In IAT 2, D scores were distributed around zero (IAT 2: $t(37) = 0.88$, adjusted $p > .99$; mean D score = 0.06). Thus, participants did not show any specific associations in this type of color-shape combinations (i.e., circle/triangle and blue/yellow). In IAT 3, D scores were distributed in the right (i.e., expected) direction (IAT 3: $t(37) = 4.65$, adjusted $p < .01$; mean D score = 0.38), which suggested a congruency effect of triangle-yellow and square-red associations (i.e., consistent with Kandinsky's color-shape associations).

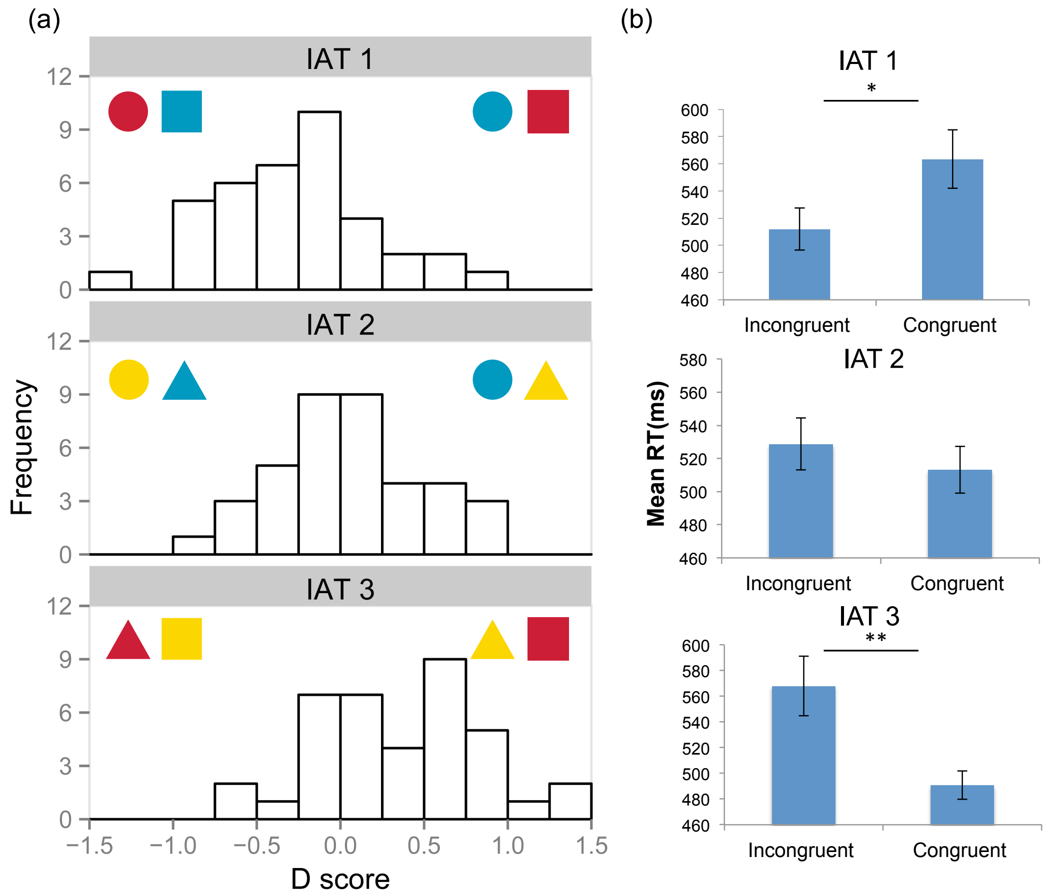


Figure 8. (a) Distribution of D scores for the three IAT tasks with Kandinsky's color-shape associations. Positive D scores indicate that trials in the left color-shape combinations were faster than those in the right. (b) Mean RTs in congruent and incongruent blocks for the three IAT tasks. Mean RTs are calculated for trials of 38 participants. Error bars represent the standard errors of the mean. "*" $p < .05$; "**" $p < .01$. Modified from Figure 2 of Chen, Tanaka, and Watanabe (in press). Copyright by the authors under a Creative Commons license. Reprinted with permission.

Response time

Mean RTs in congruent and incongruent conditions were computed (Fig. 8b). Paired *t*-tests with Bonferroni correction showed results patterns similar to that of D scores. In IAT 1, participants responded faster in the incongruent (512 ms) than in the congruent (563 ms) conditions ($t(37) = 3.04$, adjusted $p < .05$). In IAT 2, there was no significant difference between the congruent (513 ms) and incongruent (529 ms) conditions ($t(35) = 1.51$, adjusted $p = .42$). In IAT 3, participants responded faster in the congruent (490 ms) than in the incongruent (546 ms) conditions ($t(35) = 4.47$, adjusted $p < .01$).

Comparison with Makin and Wuerger (2013)

The difference of the present result and Makin and Wuerger (2013), who run the same experiments with a different set of British participants, was discussed. Here, I recruited thirty-eight Japanese college students (24 males, mean age = 21.5, *SD* = 1.5) and in Makin and Wuerger, they recruited thirty-six British participants (age 18-45, 11males) who were mostly undergraduate or postgraduate students at the university of Liverpool.

In IAT 1, D scores were significantly shifted to the left direction (mean D score = -0.26), and the RTs in the incongruent blocks (mean RT = 512 ms) were faster than those in the congruent blocks (563 ms), which indicated that most of participants associated circle with red and square with blue (i.e., opposite of Kandinsky's color-shape associations). Makin and Wuerger (2013) used the same set of color and shape stimuli (circle/square and red/blue in their IAT 2), and the D scores in their study were distributed around zero (mean D score = -0.04), and there was no significant difference in RTs ($t(35) = -1.502$, $p = 0.142$, congruent = 630 ms vs. incongruent = 601 ms). This discrepancy may need further investigations. Nevertheless, these results suggest that most people do not have circle-blue and square-red associations as proposed by Kandinsky. In addition, the previous studies using direct matching task reported circle-red and square-blue associations, which were opposite to Kandinsky's associations (Dumitrescu, 2011; Lupton & Miller, 1991; Kharkhurin, 2012).

In IAT 2, D scores were distributed around zero (mean D score = 0.06) and RTs did not show any differences between the congruent (513 ms) and incongruent (529 ms) conditions. It is likely similar to the null result in Makin and Wuerger (mean D score = -0.08; mean RT = 609 ms vs. 588 ms in the congruent and incongruent conditions, respectively). These results indicate that there was little congruency effect consistent with Kandinsky's circle-blue and triangle-yellow associations.

In IAT 3, D scores were significantly shifted to the positive direction (mean D score = 0.38), and participants responded faster in the congruent (491 ms) than in the incongruent (568 ms) condition, which suggested a congruency effect of square-red and triangle-yellow associations. This result supports Kandinsky's correspondence theory. Makin and Wuerger (2013) also observed a marginal effect in this color-shape combination; D scores were marginally shifted to the right (p = 0.05, mean D score = 0.13) and RTs in the congruent conditions (575 ms) were faster than that in the incongruent conditions (621 ms).

Explicit questionnaire

The results of the explicit questionnaire were shown in Table 7. A chi-square goodness of fit test showed that participants made some color-shape combinations more frequently than others ($x^2 = 27.99$, $df = 5$, $p < .01$). 14 out of 38 participants (36.84%) made color-shape associations consistent with Kandinsky's theory (Label 2 of Table 7) and the same number of participants (14 out of 38 participants; 36.84%) made Japanese color-shape associations (Label 1 of Table 7). However, the participants who showed color-shape associations consistent with Kandinsky's theory might be influenced by the IAT task they had performed. In the present experimental paradigms, the congruent color-shape associations appeared twice while the incongruent color-shape associations appeared only once (e.g., red-square appeared in IAT 1 and 3 while blue-square and yellow-square appeared once in IAT 1 and 3, respectively); therefore, the difference with the number of responses might affect the answers of explicit questionnaire to some extent. Accordingly, the results of explicit questionnaire indicate that most participants chose Japanese color-shape associations (Label 1 in Table 7), even under the priming effect of IAT paradigm in accordance with Kandinsky's color-shape associations.

Table 7. Explicit questionnaire results

Label	Circle	Square	Triangle	Exp. 3 (N = 38)	Exp. 4 (N = 24)
1	Red	Blue	Yellow	14 (36.84%)	13 (54.16%)
2	Blue	Red	Yellow	14 (36.84%)	3 (12.5%)
3	Red	Yellow	Blue	3 (7.89%)	4 (16.67%)
4	Blue	Yellow	Red	2 (5.26%)	3 (12.5%)
5	Yellow	Blue	Red	2 (5.26%)	0 (0%)
6	Yellow	Red	Blue	3 (7.89%)	1 (4.17%)

Interim summary

Overall, by replication of Makin and Wuerger (2013) in Japanese participants, Experiment 3 showed limited support for Kandinsky's color-shape associations. In IAT 1, the circle-red and square-blue congruency effect was observed. In IAT 3, the triangle-yellow and square-red congruency effect was observed. Interestingly, these color-shape associations have been observed in the previous studies using explicit matching task. Albertazzi et al. (2013) asked Italian participants to choose a color to best matched a shape from a color wheel (40 hue colors from NCS), and found that a circle and a square were associated with red, and a triangle was associated with yellow. Indeed, in the explicit questionnaire, the circle-red, square-blue, and triangle-yellow associations were prominent.

3.3 Experiment 4: Japanese people's color-shape associations by IAT

In order to examine whether there were any color-shape associations that could be measured and consistently shown using the IATs, the Japanese color-shape associations observed in Experiment 1 (e.g., circle-red, square-blue, triangle-yellow) was tested.

3.3.1 Method

Participants

Twenty-four new participants took part in the study (16 males, Mean = 21.0, *SD* = 1.4). All participants had normal or corrected-to-normal visual acuity and normal color vision.

Apparatus and procedure

The apparatus, shape stimuli, and color stimuli were the same with those in Experiment 3. In each IAT task, the congruent combinations of color-shape associations were changed according to the patterns of color-shape associations observed in Japanese participants (i.e., circle-red, square-blue, triangle-yellow; see Table 6). The experimental procedure was identical to that of Experiment 3.

3.3.2 Results and Discussion

Error trials (3.9%) and trials with RTs longer than 2,000 ms (1.3%) were excluded from data analysis. D scores and RTs in congruent and incongruent blocks from each of the three IAT tasks were calculated as in Experiment 3.

D scores

One sample *t*-tests with Bonferroni correction showed that the D scores of the three IAT tasks were significantly distributed in the right (i.e., expected) direction (IAT 1, $t(23) = 3.34$, adjusted $p < .05$; IAT 2, $t(23) = 3.27$, adjusted $p < .05$; IAT 3, $t(23) = 3.58$, adjusted $p < .01$). Thus, the congruency effect of the color-shape associations modulated RTs (Fig. 9a). This indicates that participants automatically associated circle with red, square with blue, and triangle with yellow, which was consistent with the color-shape associations observed by the direct matching task in Experiment 1.

Response time

RTs in the congruent and incongruent blocks from each of the IAT tasks were computed (Fig. 9b). Paired sample *t*-tests with Bonferroni correction showed that RTs were significantly faster in the congruent than in the incongruent conditions in all three IAT tasks (IAT 1, 493 ms in the congruent blocks vs. 553 ms in the incongruent blocks, $t(23) = 2.99$, adjusted $p < .05$; IAT 2, 498 vs. 548 ms, $t(23) = 3.05$, adjusted $p < .05$; IAT 3, 503 vs. 554 ms, $t(23) = 3.31$, adjusted $p < .01$). The overall mean RTs across the three tasks also showed a significant difference between the congruent and incongruent conditions (498 vs. 551 ms, $t(23) = 4.48$, adjusted $p < .05$).

In IAT 1, participants responded faster when circle-red and square-blue were assigned to the same response key (circle-red/square-blue vs. circle-blue/square-red condition; in Experiment 3: 502 vs. 544 ms; in Experiment 4: 493 vs. 533 ms; in Makin and Wuerger (2013): 601 vs. 630 ms). Therefore, participants tended to associate circles with red, squares with blue. In IAT 2, RTs in congruent conditions were significantly faster than were those in incongruent conditions, which indicated a congruency effect for circle-red and triangle-yellow links. In IAT 3, a significant difference in RTs in congruent and incongruent conditions suggested that participants responded faster in congruent conditions. This result indicates that associations between triangle and yellow and between square and blue influenced participants' RTs. In all, across the three IATs, the consistent associations of circle-red, square-blue, and triangle-yellow facilitated participants' RTs for stimulus discrimination, which provided strong evidence that color-shape associations were encoded. Thus, Japanese people's color-shape associations could influence people's stimulus discrimination and task performance at the level of response selection (i.e., circle-red, square-blue, triangle-yellow).

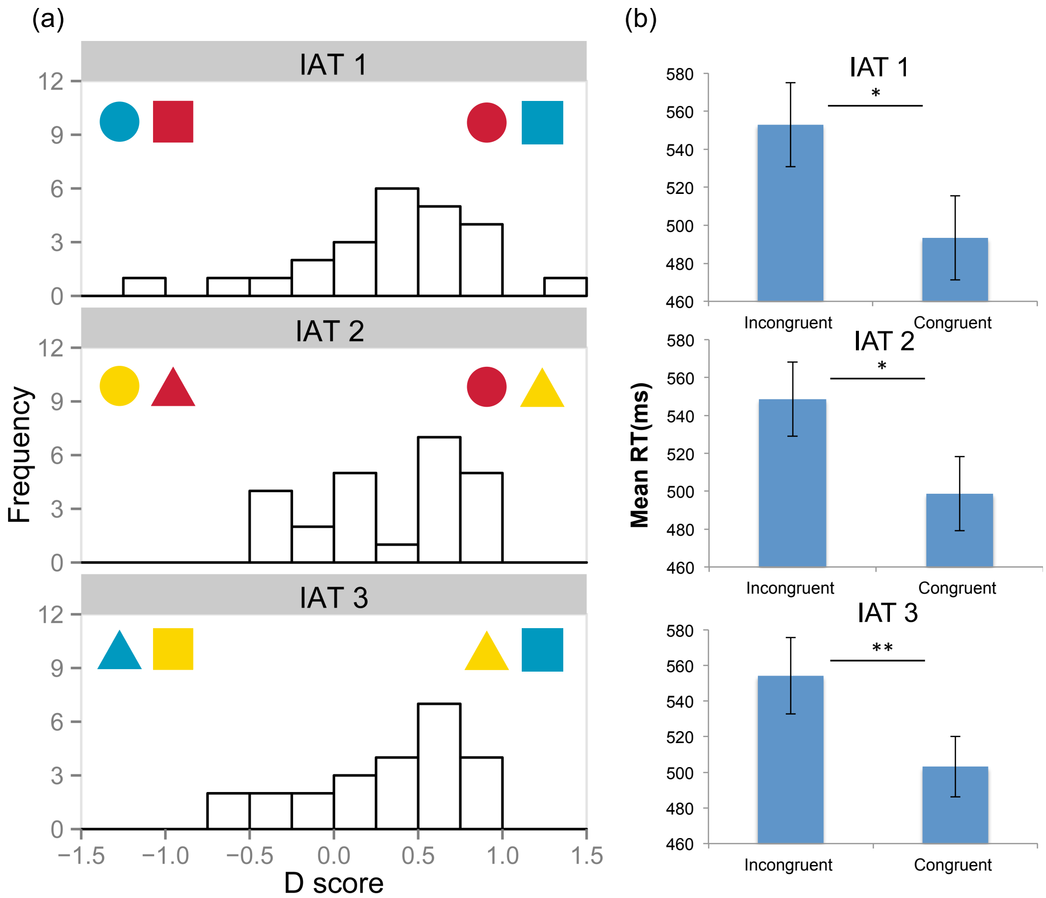


Figure 9. (a) Distribution of D scores for the three IAT tasks with Japanese people's color-shape associations. Positive D scores indicated that trials in the left color-shape combinations were faster than those in the right. (b) Mean RTs in congruent and incongruent blocks for the three IAT tasks. Mean RTs are calculated for trials of 24 participants. Error bars represent the standard errors of the mean. "*" $p < .05$; "**" $p < .01$. Modified from Figure 3 of Chen, Tanaka, and Watanabe (in press). Copyright by the authors under a Creative Commons license. Reprinted with permission.

Explicit questionnaire

Thirteen out of 24 of participants (54.17%) made color-shape combinations consistent with those of the present experimental sets (i.e., circle-red, square-blue, and triangle-yellow; Label 1 in Table 7). As only 24 participants were recruited in Experiment 4 and chosen times for circle-yellow, square-blue, and triangle-red associations were 0 (Label 5 in Table 7), participants were divided into two groups: Japanese people's color-shape associations (Label 1 in Table 7; population rate = 16.7%) and the other associations (population rate = 83.3%). A chi-square test showed that Japanese color-shape association was chosen more than the other groups ($p < .01$). However, again this could be due to the experimental paradigm with the IATs performed before the explicit matching questionnaire.

3.4 Discussion

In this chapter, I used an indirect behavioral method by the IATs to examine associations between colors and shapes, with reference to Kandinsky's correspondence theory (i.e., circle-blue, square-red, triangle-yellow; Experiment 3) and Japanese people's color-shape associations (i.e., circle-red, square-blue, triangle-yellow; Experiment 4). Results of Experiment 3 showed little evidence for Kandinsky's color-shape associations, which was consistent with the result from Makin and Wuerger (2013) obtained with British participants. In Experiment 4, participants responded more rapidly when circle-red, square-blue, and triangle-yellow were mapped onto the same response key than when they were paired with different response keys. These results suggested congruency effect of color-shape associations, in line with Japanese people's color-shape associations. Therefore, the present chapter confirmed the existence of associations between colors and shapes by an indirect behavioral experimental method.

To the best of our knowledge, this is the first study to demonstrate associations between colors and shapes using an indirect behavioral performance method. Studies using explicit matching tasks have reported different patterns of color-shape associations (Jacobsen & Wolsdorff, 2007; Albertazzi et al., 2013; Dumitrescu, 2011). However, little has been demonstrated using indirect performance tasks. Previous studies using indirect behavioral methods applied Kandinsky's correspondence theory and failed to provide clear evidence for color-shape associations (Kharkhurin, 2012; Holmes & Zanker, 2013; Makin & Wuerger, 2013). Consistent with the results of Experiment 1 using an explicit matching task (i.e., circle-red, square-blue, and triangle-yellow), this chapter verified color-shape associations using indirect behavioral experimental methods.

In Experiment 3, a congruency effect for color-shape associations in two IAT tasks were observed. In IAT 1, pairing circle-red and square-blue with the same response key enhanced RTs. In IAT 3, triangle-yellow and square-red also showed a congruency effect on RTs. In IAT 2, no color-shape association effect was observed (circle-blue and triangle-yellow). It seems contradictory that squares were paired with different colors in two IAT tasks (that is, blue and red, respectively). This might be the due to the relative strength of the different color-shape associations (i.e., circle-red, triangle-yellow, square-blue). For example, in Experiment 1, participants were asked explicitly to choose the best-matched color for a shape from a 40-hue color wheel, twice. 34% of participants chose red colors for a circle, 33% chose yellow colors for a triangle, and 19% chose blue colors for a square. Moreover, comparing the color distance between the first and second color choices, the most consistent color choice was the selection of red for the circle, suggesting a stronger, more stable link for circle with red than for the other color-shape combinations. The square showed the least consistent color choices, being associated with blue, blue-green, and green. The triangle-yellow was the second most consistent association. Those results likely reflected the relative strength of different color-shape associations. Therefore, it may be the differences on the strength of color-shape associations led to the associations in IAT 1 (circle-red) and IAT 3 (triangle-yellow), as well as the null results of IAT 2 (circle-blue). Importantly, the varying strength of the color-shape associations might be influenced by cultural background to some extent. For example, the strong association between circle and red among Japanese participants might be influenced by a salient cultural mediation factor: e.g., the Japanese flag has a red circle at the center of a white background. However, previous studies have also observed these associations in various other countries. For example, Albertazzi et al. (2013) observed circle-red, square-red, and triangle-yellow associations in Italian people. Kharkhurin (2012) conducted a color-shape correspondence survey and found a square-blue association in participants from mixed cultural backgrounds. Makin and Wuerger (2013) observed a marginal effect for square-red and triangle-yellow associations in British participants. It would be interesting in future studies to investigate possible cultural differences in color-shape associations using indirect behavioral performance measures.

In summary, the findings of Japanese people's color-shape associations in the Experiment 1 (i.e., circle-red, square-blue, and triangle-yellow) could be further verified with use of the indirect behavioral method by the IATs. The congruency effect of color-shape associations seems to influence RTs for shape and color discriminations and response selections. Thus, color-shape associations were encoded by participants, and could be strong enough to influence task performance for stimulus discrimination. These color-shape associations showed little support for Kandinsky's correspondence theory, but were fully in line with the Japanese color-shape associations.

The chapter 2 and chapter 3 demonstrated color-shape associations in Japanese neurotypical participants by using both direct and indirect experimental methods. However, whether auditory features influence those intra-visual color-shape associations is currently unknown. In the following study, in order to reveal the sounds effect on color-shape associations, I examined whether people with limited hearing experience (deaf people) also exhibited color-shape associations by both direct and indirect experimental methods, and compared the differences of color-shape associations between deaf and hearing people.

4. Color-shape association in deaf people

4.1 Introduction

Studies have found that information from different sensory modalities interacts. For example, the phonological characteristics of graphemes have been shown to influence grapheme color choices for graphemes in individuals with synesthesia. However, whether sound influences color-shape associations is currently unknown. Studies on grapheme-color synesthesia have found that people with synesthesia consistently and automatically associate specific graphemes with colors (e.g., the letter "A" is associated with color red). Most of these grapheme-color associations are triggered by visual form (grapheme), sound (phoneme), semantic content, and letter frequency (Simner, 2012; Simner et al., 2005). Recently, Asano and Yokosawa (2011) investigated synesthetic grapheme-color associations with Japanese languages. They compared the synesthetic colors induced by Japanese Hiragana and Katakana, which represent the same set of syllables with different visual forms. Asano and Yokosawa (2011) found that color choices for Hiragana characters and their Katakana counterparts were remarkably consistent. This suggested that grapheme-color associations might depend on the phonological characteristics associated with the graphemes, and not as much on the visual form (shape) of the graphemes. Asano and Yokosawa (2012) also reported that synesthetic color choices for Japanese Kanji characters depended on the phonological information or the semantic meaning of the graphemes. However, it is still unclear whether phonological information influences color-shape associations.

Studies on cross-modal interactions suggested that information input from one sensory modality influences information processing in other sensory channels (Spence, 2012). For example, Fryer, Freeman, and Pring (2014) tested "Bouba-Kiki" effect in the auditory-haptic modalities ("Bouba-kiki" effect refers to the phenomenon that people tend to match sharp angular shapes with sounds "kiki", and round shapes with sounds "bouba"; Kohler, 1947; Ramachandran & Hubbard, 2001). Participants were instructed to touch and choose a shape that they could not see (shape models were with sharp or round edges in different materials), to match with the sounds of "bouba" or "kiki". They found that sighted participants showed a robust "Bouba-Kiki" effect, while in a sample with a range of visual impairments, the effect was significantly less pronounced from congenital total blindness to partial sight. Thus, in the absence of a direct visual stimulus, visual imagery plays a role in cross modal interaction between auditory and haptic modalities. Information input from different sensory modalities might influence the cross modal integration and interaction.

The chapter 2 and 3 demonstrated that Japanese people with normal hearing have systematic color-shape associations, which could be explained by the existence of semantic information common to colors and shapes (e.g., warm/cold). According to the aforementioned studies, phonological characteristics might influence color-shape associations (Asano & Yokosawa, 2011, 2012). However, little is currently known about the influence of sounds on color-shape associations. In order to dissociate the sound effect on color-shape associations, I explore color-shape associations in deaf people, using both direct (explicit questionnaire survey) and indirect (IATs) experimental methods, and compared with that of normal hearing people. If consistent color-shape associations were observed between deaf and hearing participants, this might indicate that the sounds or hearing experiences have little effect on color-shape associations. On the other hand, if different color-shape associations were observed between the two groups, it might suggest that the phonological characteristics of colors and shapes, or the hearing experience, modulate color-shape associations.

In Experiment 5, I designed a questionnaire survey based on the findings of Experiment 1, directly investigated color-shape associations in deaf and control people with normal hearing. In Experiment 6, I adopted the indirect IAT task, using the same experimental paradigm as the previous Experiment 4 on deaf people, and compared with that of hearing people.

4.2 Experiment 5: Explicit questionnaire on color-shape associations

4.2.1 Method

Participants

Ninety-one college students (32 female, mean age = 21.2, *SD* = 1.3) from the Tsukuba University of Technology participated, all of whom had an auditory threshold level of at least 60 db (hereafter called deaf participants). All participants had normal or corrected-to-normal visual acuity and normal color vision. Experiment 5 and 6, with deaf participants, were approved by the institutional review board of The National University Corporation of Tsukuba University of Technology.

Ninety-five college students with normal hearing (41 female, mean age = 21.6, *SD* = 2.9) took part in the experiment as a control group. The control experiment with hearing participants was proved by the institutional review board of The University of Tokyo.

Apparatus and stimuli

A questionnaire survey designed to examine the associations between the basic shapes (i.e., circle, square, and triangle) and the four colors (i.e., red, yellow, blue, and green) was conducted. It was printed on two pages of A4 papers. In the first page, participants were instructed to choose which color of the four colors best matched for a presented shape. There were three basic shapes (i.e., circle, triangle, and square), which randomly presented in a column on the left side of the paper across participants. On the right side of the paper, besides each shape, a color wheel filled with four colors (i.e., red, yellow, blue, and green) was presented, which also randomly arranged across participants. The color stimuli were the basic color categories (e.g., red, yellow, blue, and green). Participants were instructed to choose the best matched color for each shape by a mark on the color patch using a pen. In the second page, the confidence of the color choice was investigated to see whether the other peers would select the same color choice for each shape. Participants were asked to rate "Do you think your peers will respond in the same way as you are?" The responses were marked on a five-point horizontal scale shown below the question with five options, displayed form left to right: "definitely no", "maybe no", "not sure", "maybe yes", and "definitely yes". The questionnaire is shown in the Appendix.

The printed questionnaires were distributed to deaf participants at the Tsukuba University of Technology. Meanwhile, the control experiment survey with hearing participants was performed in the University of Tokyo. The questionnaire survey was conducted in a lighted laboratory with each participant individually. The answered questionnaires were collected. The whole experiment lasts 5 minutes.

4.2.2 Results and Discussions

Choosing frequency of colors for shapes

The choosing times of colors for each shape in deaf and hearing people were calculated. Table 8 shows the choosing frequency of colors for shapes. In order to compare the color choices for shapes between the two groups of people, a log-linear analysis was used to examine the relationships between color, shape, and population. A three-way log-linear analysis, shape (3) × color (4) × population (2), for the accumulated choice times of colors for shapes in both hearing and deaf people was used to examine the relationships between color, shape, and population. Results showed a best-fitting model, which included shape, color, and shape-color interactions. Besides, significant main effect of color (x^2 = 8.35, df =

3, $p < .05$), and significant interactions between shape and color ($x^2 = 252.61$, $df = 6$, $p < .01$) were observed. Those results suggested that color choices for shapes were not random. However, a significant main effect of population ($x^2 = 0.26$, $df = 1$, $p = .61$), or significant interactions between population and color ($x^2 = 1.99$, $df = 3$, $p = .57$), or significant interactions between population, color, and shape ($x^2 = 12.04$, $df = 6$, $p = .06$) were not observed. Thus, the color selections for shapes in the two groups of deaf and hearing people have no significant difference.

Table 8. Choosing frequency of colors for shapes in deaf and hearing participants (%).

		Red	Yellow	Blue	Green
Circle	Hearing	**61.05**	24.21	7.37	7.37
	Deaf	**64.84**	8.79	16.48	9.89
Triangle	Hearing	18.95	**47.37**	16.84	16.84
	Deaf	20.88	**46.15**	9.89	23.08
Square	Hearing	7.37	9.47	**47.37**	35.79
	Deaf	5.49	12.09	**48.35**	34.07

Note: Cells in bold indicate a significant association between color and shape, p < .05.

As the best-fitting model retained a significant interaction between color and shape, and there was no significant difference on color-shape associations between deaf and hearing participants, in order to break the interactions down, a post-hoc chi-square test was conducted for further analysis to reveal significant color-shape associations. Results showed that for each shape, there were significant different choices of color assignment (circle: $x^2 = 144.97$, $df = 3$, $p < .01$; triangle: $x^2 = 49.09$, $df = 3$, $p < .01$; square: $x^2 = 86.90$, $df = 3$, $p < .01$). Multiple comparisons using Ryan's method (Hsu, 1996) showed that some colors were significantly more frequently chosen for shapes than other colors (Fig. 10). For example, for circle, red were chosen more than others (62.90%); for triangle, yellow were chosen more frequently than others (46.77%); for square, blue and green were more frequently chosen (blue: 47.85%, green: 34.95%). Those results suggested strong color-shape associations between circle and red, triangle and yellow, and square with blue or green both in hearing and deaf participants.

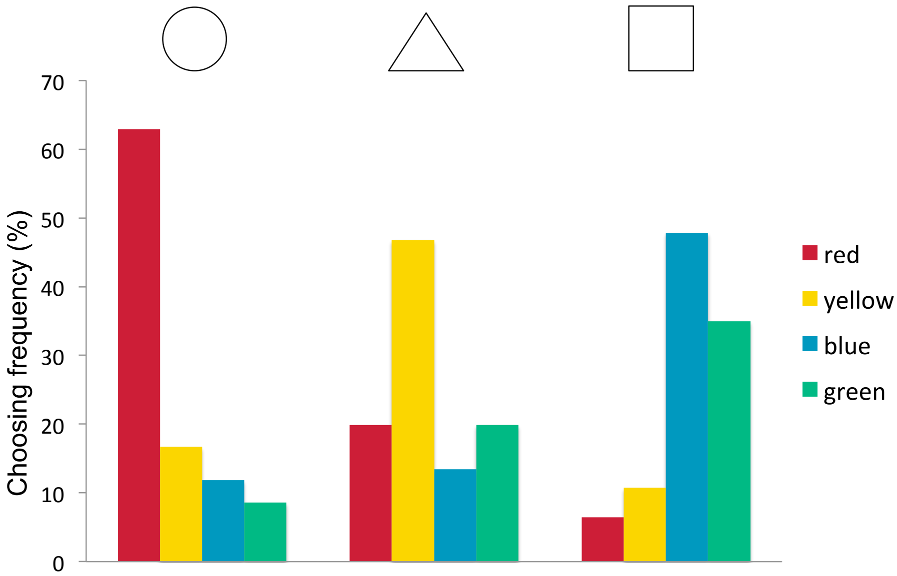


Figure 10. Choosing frequency of colors for shapes. Note that data of hearing and deaf participants were combined.

Confidence ratings

In the second page of the questionnaire, participants were asked to rate the confidence that their peers would make the same color choice as them on a five-point scale. The answer of "definitely no" is marked as 1, and the answer of "definitely yes" is rated as 5, and those other answers are rated averagely across the five ratings.

The confidence ratings for each of color-shape combinations were averaged (Fig. 11). The choice numbers for each color-shape combinations were different, for example, the sample number of confidence ratings of red for circle was more than the choice numbers of other colors (59 versus 32 in deaf people; 58 versus 37 in hearing people). Thus, I used the unpaired *t*-test to examine whether the confidence rating of specific color for each shape was significantly larger than that of other colors both in deaf and hearing people.

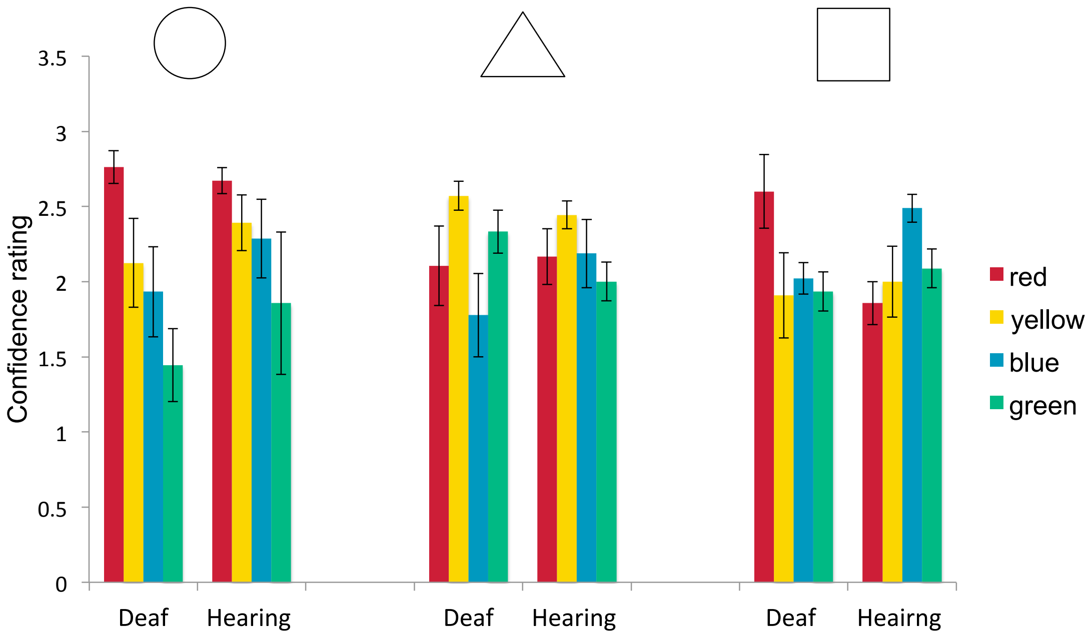


Figure 11. Confidence ratings of each color-shape combinations in deaf and hearing people. Means are calculated for participants. Error bars represent the standard errors of the mean.

For circle-red association, confidence ratings with color red were compared with confidence ratings for the rest three colors. Unpaired *t*-test showed that both deaf and hearing people were more confident in the circle-red association than circle with other colors (deaf: $t(89) = 4.69$, $p < .01$, mean rating of circle-red versus that of circle-other colors: 2.76 vs. 1.83; hearing, $t(93) = 2.46$, $p < .05$, mean rating of circle-red versus that of circle-other colors: 2.67 vs. 2.18). Both deaf and hearing participants tended to have high confidence in circle-red linkages than circle with other colors. The comparison on confidence ratings of circle-red association between deaf and hearing participants showed that there was no significant difference ($t(115) = 0.65$, $p = .52$; mean rating of circle-red in deaf versus that in hearing: 2.76 vs. 2.67).

For triangle-yellow association, unpaired *t*-test was used to examine the difference between confidence ratings of yellow with triangle and that of the rest other colors. Results showed that both deaf and hearing people tended to be more confident at the triangle-yellow link than triangle with other colors (deaf: $t(89) = 2.56$, $p <.05$, mean rating of triangle-yellow versus that of triangle-other colors: 2.57 vs. 2.07; hearing: $t(93) = 2.28$, $p < .05$, mean rating of triangle-yellow versus that of triangle-other colors: 2.44 vs. 2.11). Comparison between deaf and hearing people on the confidence ratings of triangle-yellow showed that there was also no significant difference between the two groups of people ($t(85) = 0.94$, $p = .35$; mean rating of triangle-yellow in deaf versus that in hearing: 2.57 vs. 2.44).

For square-blue and square-green associations, the unpaired *t*-test showed that for deaf people, there were no significant difference on confidence ratings of blue or green for square with the rest colors (blue: $t(89) = 0.15$, $p = .88$, mean rating of square-blue versus that of square-other colors: 2.02 vs. 2.14; green: $t(89) = 0.7$, $p = .49$, mean rating of square-green versus that of square-other colors: 1.93 vs. 2.18). Those results indicated that deaf people were not confident at the blue or green choices for square. In hearing participants, the confidence ratings of blue for square were significantly higher than that of the rest colors ($t(93) = 3.28$, $p < .01$, mean rating of square-blue versus that of square-other colors: 2.49 vs. 1.98). Confidence ratings of green for square showed no significant difference with that of the rest other three colors ($t(93) = 1.72$, $P = .09$, mean rating of square-green versus that of square-other colors: 2.09 vs. 2.11). Thus, hearing participants showed confidence at the square-blue combination. Comparison between deaf and hearing people on the confidence ratings of square-blue and square-green showed that there were significant difference on the square-blue confidence ($t(87) = 3.32$, $p < .01$, mean rating of square-blue in deaf versus that in hearing: 2.02 vs. 2.49), that hearing participants tended to be more confident at the square-blue associations than deaf participants. Besides, there was no significant difference on square-green confidence between deaf and hearing people ($t(63) = 0.83$, $p = .41$, mean rating of square-green in deaf versus that in hearing: 1.94 vs. 2.09), indicated that both deaf and hearing people showed no confident at square-green associations.

Combining with the results of explicit matching and confidence rating tasks, both deaf and hearing showed specific color-shape associations (i.e., circle-red, triangle-yellow, and square-blue), consistent with the findings in Experiment 1. Moreover, both deaf and hearing people were confident with some color-shape associations (i.e., circle-red and triangle-yellow combinations). However, the color choices of blue for square in deaf were less confident than that in hearing people, which indicated a weak square-blue association in deaf people. Besides, square-green associations tended to be the least confident associations both in deaf and hearing people.

In all, there was no significant difference on color-shape associations in deaf and hearing participants revealed by the explicit questionnaire. Deaf participants have similar patterns and confidence ratings for color-shape associations as circle-red, triangle-yellow, and square-blue links with hearing participants.

In the chapter 2, I used an explicit matching task to reveal color-shape associations in normal hearing Japanese people, and the present results were consistent with that, such as circle-red and triangle-yellow links. A semantic rating task suggested that color-shape associations might stem from the common semantic information between colors and shapes (e.g., warm/cold), which people tend to match warm/cold colors to warm/cold shapes leading to the color-shape associations. Here, deaf and hearing people established similar patterns of color-shape associations. It might indicate that deaf people's color-shape associations could also be interpreted by the semantic sensory correspondence between color and shape, and it might be little influenced by hearing experience.

As stated in chapter 3, using direct matching task may not fully understand color-shape associations, in the following Experiment 6, I also used the indirect behavioral method (i.e., IATs) to examine the strength of color-shape associations in deaf people.

In chapter 3, color-shape associations could be measured and proved by the IAT tasks in hearing people. The congruency effect of color-shape associations accelerated response selections for stimulus discrimination, suggested that color-shape associations were encoded and could be strong enough to influence task performance in hearing people. However, whether deaf people's color-shape associations could also be strong enough to be measured and proved by the indirect behavioral task (e.g., IAT) is currently unknown. In Experiment 6, I used the same IAT experiment paradigm as in Experiment 4, to examine whether deaf people's color-shape associations could be tested by the IATs.

4.3 Experiment 6: Deaf people's color-shape associations by IAT

4.3.1 Method

Participants

Twenty college students of Tsukuba University of Technology whose hearing threshold level was over 60db participated in this experiment (8 female, mean age = 21.1 year old with *SD* = 1.0), which hereafter called deaf participants. All participants had normal or corrected to normal visual acuity and normal color vision.

Apparatus and procedure

The experimental paradigm was the same as in Experiment 4. Stimuli were presented on a 1280 × 1024 pixel CRT monitor, with a refresh rate of 60 Hz. The shape stimuli were drawn in white lines (with a width of 26mm, 0.03° visual angle) on a black background (8 cd/m^2). The circle was 4.8° in diameter, the square was 4.8° (in height) × 4.8° (in width), and the triangle was 4.8° (in height) × 5.8° (in width). The shape stimuli were presented in the upward orientation. The color stimuli were three color patches that were ~9.5° wide (Gaussian-modulated). The colored Gaussian patches were measured using PR-655 (Photo Research, Chatsworth, CA, USA) and each color was consecutively measured 10 times and averaged. The color information was described in terms of (L*, a*, b*): yellow (47.5, 3.07, 59.47), red (18.74, 36.53, 26.03), blue (21.07, -2.6, -21.17).

In each IAT task, the congruent and incongruent combinations of color-shape associations were same as in Experiment 4, observed in normal Japanese participants (i.e., circle-red, square-blue, triangle-yellow; Table 6). The experiment procedure was also identical to that of the Experiment 4 except for the questionnaire after the IAT task was eliminated (Experiment 5 used the explicit questionnaire survey already).

4.2.2 Results and Discussion

One participant, whose error rate more than 12%, was excluded from data analysis. Additionally, error trials (4.5%) and trials with RTs' longer than 2,000 ms were excluded from data analysis. The same analysis methods were used here as in Experiment 3, i.e., using D scores and RTs.

D score

One-sample *t*-tests with Bonferroni correction were used to compare D scores with zero. D scores in all three IAT tasks were normally distributed around zero (IAT 1: $t(18) = 0.54$, adjusted $p > .99$, mean D score = 0.06; IAT 2: $t(18) = 1.61$, adjusted $p = .78$, mean D score = 0.21; IAT 3: $t(18) = 1.06$, adjusted $p > .99$, mean D score = 0.11; Fig. 10a). Hence, in each IAT task, deaf participants showed no specific tendency to associate specific colors with particular shapes.

Response time

For each IAT, mean RTs for congruent and incongruent conditions (Fig. 10b) were computed. Paired sample *t*-tests with Bonferroni correction did not show any significant differences in RTs between congruent and incongruent conditions in any of the three IAT tasks (IAT 1: $t(18) = 0.74$, adjusted $p > .99$, 543 ms in the congruent condition vs. 554 ms in the incongruent condition; IAT 2: $t(18) = 1.14$, adjusted $p > .99$, 545 ms vs. 571 ms; IAT 3: $t(18) = 1.45$, adjusted $p > .99$; 551 ms vs. 576 ms). Comparing congruent and incongruent conditions, using the average mean RTs over the three tasks, also failed to show any significant difference ($t(18) = 1.93$, adjusted $p = .42$, 546 ms vs. 567 ms).

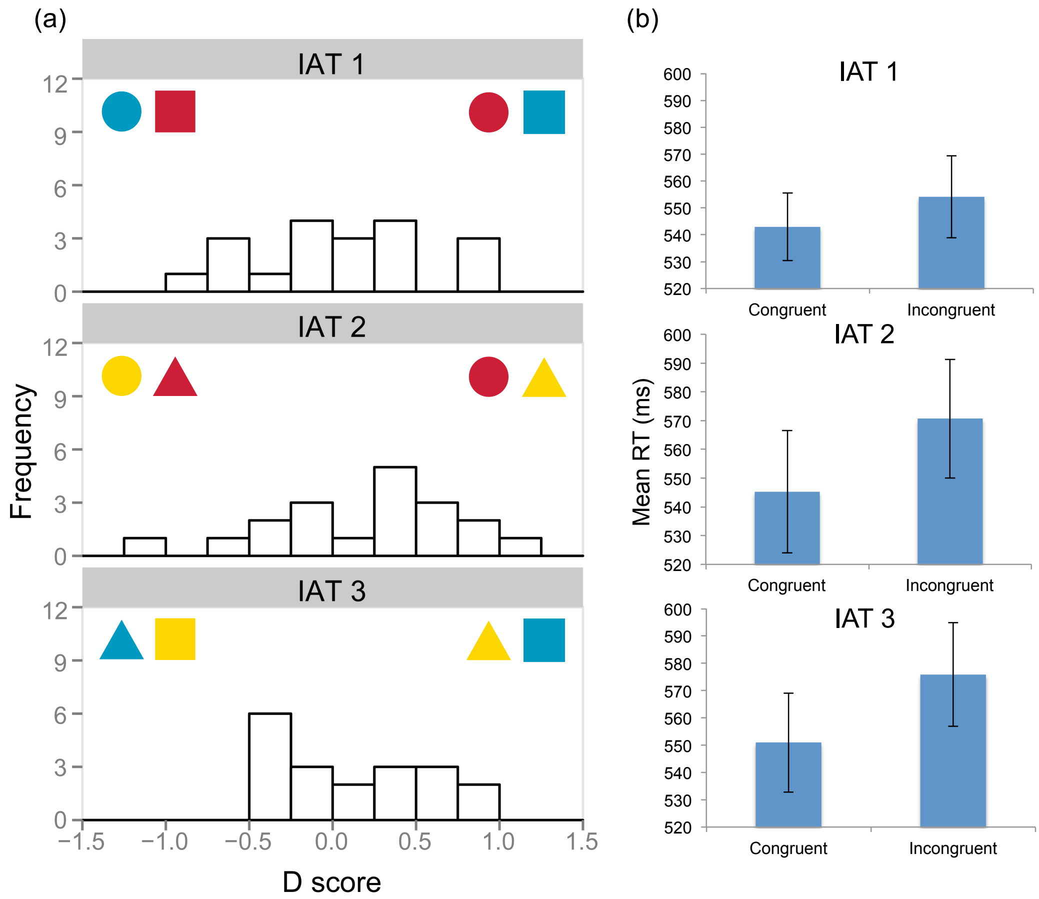


Figure 12. (a) Distribution of D scores for the three IAT tasks with Japanese color-shape associations. Positive D scores indicate that trials in the left color-shape combinations were faster than those in the right. (b) Mean RTs in congruent and incongruent blocks for the three IAT tasks. Mean RTs are calculated for trials of 19 participants. Error bars represent the standard errors of the mean.

Considering the results of D scores and RTs, there was little evidence for the hypothesized color-shape associations (i.e., red-circle, yellow-triangle, and blue-square) in deaf participants. Thus, the IAT revealed that deaf people have weak or limited color-shape associations.

Comparison between deaf and hearing people

Combining the results of Experiments 4 and 6, task performance of deaf and hearing people on the IATs were compared. As the number of deaf and hearing participants was different (19/24), a bootstrap method was used here.

First, the re-sampled D scores in deaf (N = 19) and hearing participants (N= 24) were compared with zero. For deaf participants, results with 2000 bootstrap samples showed only the IAT 2 produced a marginal effect (p = .08), with the IAT 1 and IAT 3 providing null results (ps > .10). For hearing participants, re-sampled D scores with 2,000 bootstrap samples showed all three IAT tasks revealed significant differences from zero (all ps < .01). This indicates that hearing individuals exhibited a significant congruency effect of color-shape associations across the three IAT tasks, while deaf people only showed a weak circle-red/triangle-yellow effect in IAT 2.

Then, whether the re-sampled D scores in hearing participants by the number of deaf (N = 19) were still higher than zero was examined. Significant positive results were found for all three IATs (all ps < .01), indicating that any 19 out of 24 hearing participants all revealed significant color-shape associations consistent with the hypothesis.

Subsequently, whether the re-sampled D scores in hearing individuals (N = 24) were larger than those in deaf cohort (N = 19) was examined. There were significant differences in IAT 1 (p < .05), the effect in IAT 3 approached significance (p = .06), and there was no difference in IAT 2 (p = .25).

Next, between-subjects one-way ANOVA was conducted to compare D scores and mean RTs in hearing and deaf participants. There was significant difference in D scores between the two groups ($F(1, 41) = 4.48$, $p < .05$), and no difference on the three IAT tasks ($F(2, 82) = 0.15$, $p = .85$), indicating that deaf and hearing people have consistently different D scores. A between-subjects three-way ANOVA (3 IAT tasks × 2 hearing groups × 2 conditions) on the RTs revealed a marginal effect on the interaction between hearing status and conditions ($F(1, 41) = 4.03$, $p = .05$). This suggests that deaf and hearing people had different RTs for congruent and incongruent conditions across the three IATs. Besides, results showed no main effect of hearing versus deaf status ($F(1, 41) = 2.44$, $p = .12$), or IAT task ($F(2, 82) = 0.55$, $p = .57$), but a significant difference between congruent and incongruent conditions ($F(1, 41) = 4.03$, $p = .05$). Taken together, these results provided further evidence that deaf and hearing people had different performance in the IAT tasks, and revealed that the former had weak color-shape associations as compared with hearing people.

4.3 Discussion

In this chapter, deaf people's color-shape associations were examined, using both direct explicit questionnaire survey and indirect behavioral performance task. Both deaf and hearing people have similar patterns of color-shape associations through the explicit questionnaire survey (e.g., circle-red, triangle-yellow, and square-blue), consistent with the findings in Experiment 1. However, deaf people showed limited and less congruency effect of color-shape associations than hearing people in the indirect behavioral task by the IATs.

In the explicit questionnaire survey, participants could have considering the color-shape combinations in a relatively long period, which may be influenced by the prototype effect. That is, people may unconsciously refer to the colored-objects encountering in the surrounding environment. For example, circle-red associations might be influenced by the red-sun national flag image, and the triangle-yellow associations might be influenced by the Egypt-pyramid effect.

In the study 1 of chapter 2, I suggested that color-shape associations could be semantically mediated correspondence. Semantic information common to colors and shapes leads to color-shape associations (e.g., warm/cold). The semantic sensory correspondences could also interpret deaf people's color-shape associations. For example, both deaf and hearing people could perceive circle and red to be warm, and square and blue to be cold, which lead to similar color-shape associations. According to the semantic coding hypothesis (Martino & Marks, 1999), there are two parts in the semantically mediated correspondence. First, with time and experience, perceptual information was incorporated into language; second, correspondence arise form the recoding of perceptual information into a common semantic basis.

Deaf people established similar intra-visual associations between colors and shapes using explicit method, which indicated that the sound or hearing experience might have little effect on the explicit color-shape associations. Studies on word symbolism suggested that normal people consistently match sounds with tactile, motor sensation, and the proprioceptive. Deaf children were also exhibited the same mapping as children and adults with normal hearing. For example, the words "k" and "r" are rated harder than "l" in both deaf children and hearing controls (Fonagy, 1963, 2001). Thus, both deaf and hearing people could incorporate perceptual information into semantic meanings, and crossmodal correspondence could occur when coding perceptual information into a semantic format. It provides the same mechanism that deaf children shared the same sound-tactile mapping as normal people (Fonagy, 2001).

In the indirect behavioral task, deaf people showed weak and less pronounced compatible effect of color-shape associations compared with hearing people. It suggested that the sound or hearing experience could influence color-shape associations to some extent. According to semantic sensory correspondence, correspondences occur as perceptual information encoded into a common semantic format, which was mediated with the language development. With limited hearing experience, deaf people might have weak language developing system, which influenced the perceptual information encoding into semantic basis. Furth (1966, 1973) proposed that language impairment associated with auditory impairment limits hearing-impaired children's experience with the world. Those experiential deficiency leads to a lag in cognitive development, which results in different performance patterns compared with normal children on perceptual and cognitive tasks. Therefore, the language impairment might influence deaf people's task performance to reveal the implicit associations between colors and shapes.

The IAT task tested the strength of unconscious associations between dimensions. Deaf people failed to reveal any compatible effect of color-shape associations, which suggested that color-shape associations in deaf people tend to be weak. Moreover, It further suggested that the hearing experience plays some part in the strength of color-shape associations. As suggested by the semantic sensory correspondence, the language development plays a key role. The experiential deficiency of hearing and language impairment may lead to weak semantic correspondence between color and shape. Deaf people exhibited explicit color-shape associations, but which might not be encoded, thus could not be measured by the indirect behavioral task. Those results indicated that semantic sensory correspondence might also account for color-shape associations in deaf people.

Additionally, the perceptual compensation hypothesis suggested that a deficit in one sensory system might cause a compensatory proficiency in the other sensory system (Hoemann, 1978; Olson, 1967; Siple, Hatfield, & Caccamise, 1978). The cortical area that is normally devoted to the deprivation modality tends to be used by some other modality. For instance, visual event-related potentials tend to be enhanced in early deaf individuals

(Neville, Schmidt, & Kutas, 1983; Neville & Lawson, 1987). The color-shape associations might be influenced by visual characteristics and perceptual interactions between visual colors and shapes. Deaf people might have enhanced visual perception, thus the congruency of color-shape associations might be weaken.

In all, deaf people have explicit color-shape associations, which were consistent with hearing people (i.e., circle-red, triangle-yellow, square-blue). But in the indirect behavioral tasks, deaf people showed less pronounced color-shape association effect as hearing people. Thus the hearing or sound experience or language development influences color-shape associations. Combining with results in the chapter 2 and 3, semantic sensory correspondence might account for color-shape associations both in deaf and hearing people. In the next study, I further examine whether semantic sensory information also mediate associations in other domains such as cross-preference.

5. Cross-preferences for color and shape

5.1 Introduction

People have specific preferences toward different objects and aspects of the world. For example, we may prefer some colors to others, or like some specific shapes or patterns rather than others. These preferences affect everyday judgments and decisions, such as what kind of clothing to wear, or which car to buy (Palmer, Schloss, & Sammartino, 2013). Hence, learning how human visual preferences are structured gives insights into the role of visual cues in shaping decisions and behaviors, which is also important for product design and marketing.

Individual differences

Color and shape preferences vary greatly among individuals. Studies have shown correlations between color preferences and individual personality traits, psychiatric disorders, internal arousal levels, creativity, and training in art (Lusher & Scott, 1969; Lusher, 1971; Lange & Rentfrow, 2007; French & Alexander, 1972; Rosenbloom, 2006; Hayashi, 2011). Lange and Rentfrow reported that introverted people (i.e., people with high internal arousal) preferred cooler colors, such as blues and greens, while extroverts (i.e., people with low internal arousal) were drawn to warmer colors, such as reds and oranges. Hayashi (2011) examined the relationship between color preferences and Big-Five personality traits, finding that preferences for pink and black were positively correlated with openness to experience, and preferences for color blue-green were negatively correlated with conscientiousness. Palmer and Schloss (2010) suggested that color preference stemmed from the affective response to color-associated objects. Individual color preference was positively correlated with preference for the average valence of objects associated with the color.

However, objects preference might be related to object shapes, textures, exposure familiarity, and semantic meanings. Therefore, color preferences could change through learning experience throughout the lifespan (Palmer & Schloss, 2010; Strauss, Schloss, & Palmer, 2013; Taylor, Schloss, & Palmer, 2013). Moreover, gender differences in color preference have been reported among Western adults. In particular, men tend to prefer saturated colors while women tend to prefer desaturated colors. These differences are strongly correlated with observers' judgments on how active/passive colors are, with males generally preferring more active colors and females preferring more passive ones (Palmer & Schloss, 2011).

Similar to color preferences, preferences for shapes vary across individuals, and are influenced by gender, age, birth order, cognitive style, creativity level, personality traits, and extent of training in art (Barron, 1963; Eisenman & Robinson, 1967; Taylor & Eisenman, 1964; Eisenman, 1967; Eisenman & Johnson, 1969; Eisenman & Gellens, 1968). Among many factors that influence visual shape preferences, the complexity-simplicity domain is one of the most studied elements, suggesting that a moderate level of internal arousal influences preference judgment (Birkhoff, 1933; Eysenck, 1941, 1942; Munsinger & Kessen, 1964). Eysenck (1940) found that individual preference for polygons could be accounted for a bipolar factor that divided the people preferring "simple" figures from those preferring "complex" figures. Preference for complexity versus simplicity is related to individual personality traits and creativity (Schroder, et al., 1967). Bryson and Driver (1972) reported that extraverts prefer moderate levels of complexity, complex introverts prefer the simplest stimuli, and simple introverts prefer the most complex stimuli. Additionally, creative individuals tend to prefer complexity to a greater extent than less creative individuals

(Barron, 1963; Eisenman, 1968a, 1968b). Cox and Cox (2002) showed that preferences for complexity-simplicity visual product designs mediated exposure preference. McManus, Cook, and Hunt (2010) showed strong and varied individual differences in preferences for rectangles, and reported no significant correlations with individual personality measures such as the Big Five personality traits (McManus, Cook, & Hunt, 2010).

Cross preference

Eysenck (1940) studied peoples' aesthetic preferences for several domains (i.e., colors, shapes, volumetric location, and music), and found preferences were correlated among individuals across those domains. He proposed a general "T" factor (which he called "good taste") to interpret these cross-individual preferences. Recently, Palmer and Griscom (2013) suggested that preferences for "harmony" could underlie Eysenck's "T" factor. They found that individual preferences for four different domains (i.e., color, shape, volumetric location, and music) correlated with "harmony" judgments for the same stimuli; some individuals preferred harmonious stimuli while others disliked them. Specifically, individuals who preferred harmonious color combinations also tended to prefer shapes with figural goodness, "good fit" volumetric location, and harmonious music. Individual preferences for the common "harmony" shared among the four domains might underlie cross-preferences for those domains.

In addition to the studies on preferences for visual stimuli, studies of human mate preferences have also shown correlations between preferences for different domains (Cornwell, et al, 2004; Feinberg, et al., 2008; Fracorro, et al., 2010). Feinberg et al. (2008) found that people who prefer male vocal masculinity also tend to prefer male facial masculinity, and suggested that men's faces and voices reveal common information about the masculinity of the sender; these multiple quality cues could be used in conjunction to determine the overall quality of individuals (Feinberg, et al., 2008). Similarly, Fraccaro et al.

(2010) reported correlated preferences in males for femininity in female faces and voices, such that male preferences for feminized versions of female faces were positively correlated with their preferences for feminized female voices. Individual mate preferences were concordant across sexually dimorphic traits in different domains, such as faces and voices, and the preference for “masculinity” or “femininity” overlapped in those domains, playing a vital role in explaining the cross-preferences.

Based on the previous findings, we can see that individual preferences within different domains are not independent, but can be correlated. Individuals who prefer specific types of information in one domain might also tend to prefer similar information in other domains. This preference for common information shared among different domains might account for cross-preference, which might be modulated by individual “taste” or personality traits. Thus, individual preferences for the two basic visual domains of colors and shapes might be correlated through a preference for semantic information common to them.

There exists substantial evidence that colors and shapes express semantic information. For example, colors can be described as “warm” and “cold”, “heavy” and “light”, “soft” and “hard”; shapes can be expressed as “dark” and “bright”, “round” and “sharp” (Ballast, 2010; Nakano, 1972; Liu, 1997; Liu & Kennedy, 1993). Some colors and shapes show common semantic information (e.g., warm/cold), which may determine the natural associations between colors and shapes (Albertazzi, et al., 2013). Some studies have reported that preferences for visual stimuli are affected by the semantic information conveyed by the stimuli (Bar & Neta, 2006; Palmer & Schloss, 2010; Ou, et al., 2004). It is therefore easy to conceive that individuals who prefer a particular type of semantic information in colors might also tend to prefer that information in shapes.

Even though individual preferences vary enormously, individual preferences for different domains might be correlated to some extent. As basic colors and shapes likely convey some common or associated semantic information, individual preferences for colors and shapes would be correlated through preferences for semantic information common to both. That is, if an individual prefers a specific color, he or she may also prefer shapes that have semantic information congruent with that color.

As semantic information could account for the general associations between colors and shapes, whether it would mediate associations in preference domains was examined. In this chapter, I investigate the relationships between preferences for colors and shapes using an individual differences approach. The hue color stimuli were the 40-hue colors from the Natural Color System and geometric shapes that differed in dimensionality (i.e., 2D versus 3D shapes) and complexity to investigate whether preferences for colors and shapes are correlated.

5.2. Experiment 7: Cross-preferences for color and shape

5.2.1 Method

Participants

One hundred and thirty-seven Japanese college students participated in this experiment (52 females and 85 males; mean age = 21.5, *SD* = 2.8). All participants had normal or corrected to normal visual acuity and normal color vision.

Apparatus and stimuli

Experiment was conducted in the same condition as in other experiments, that stimuli were displayed centrally on a 15.5-inch LCD color monitor, controlled by a laptop computer, with 1920 × 1080 resolution and a refresh rate of 60 Hz. Participants viewed the monitor at a distance of approximately 60 cm. The visual stimuli consisted of 40 rectangular colors (7.1 cm × 5.3 cm; 6.7° × 5° in visual angle), and 12 line-drawing shapes including three basic 2D shapes (circle, triangle, and square), and three types of 3D shapes (cone, pyramid, and truncated-pyramid). The 40 colors were the same color stimuli used in other experiments.

Shape complexity is an important visual feature in shape perception, which could influence an individual's internal arousal and therefore influence preference judgments (Bryson & Driver, 1972). Fluency theory suggests that people prefer visual stimuli to the extent that they are processed more easily (Reber, Schwarz, & Winkielman, 2004; Reber, Winkielman, & Schwarz, 1998). In order to examine whether shape complexity would influence the relationships between preferences for colors and shapes, we used basic 2D and 3D shapes, and created levels of complexity shapes according to the number and structure of lines based on the 3D shapes (i.e., silhouette of 3D shapes, normal 3D shapes, and scrambled 3D shapes). Three types of outlined silhouette of 3D shapes (i.e., silhouette cone, silhouette pyramid, and silhouette truncated-pyramid) were created and perceived as simple shapes, and three types of scrambled 3D shapes (scrambled cone, scrambled pyramid, and scrambled truncated-pyramid, generated by changing the direction of the lines that formed the 3D shapes; Fig. 13a) were created as complex shapes.

Studies suggested that different levels of shape size and spatial rotation might convey different semantic information, which influence the shape preference (Palmer, Schloss, & Sammartino, 2013). For example, people tend to prefer larger shapes than smaller ones (Silvera, Josephs, & Giesler, 2002), and stimuli that tend to be easily processed (Reber, Schwarz, & Winkielman, 2004; Reber, Winkielman, & Schwarz, 1998). Thus, I examined the size and rotation effect on shape preference. Three sizes of the shape stimuli, namely small, medium, and large were used. The large size was approximately four times the area of the medium size, and the small size was approximately one-sixteenth the area of the medium size. Volumetric rotation levels were prepared with each shape rotated 0°, 15°, and 345°. As circle could not be rotated, I modulated only size of circle. By contrast, the other eleven shapes could be rotated; I modulated size and rotation of these shapes. Thus, there were 102 shape stimuli in total (11 shapes × 3 sizes × 3 rotations + 1 shape × 3 sizes = 102 shapes).

The geometric shapes were all drawn in black lines of 2.6 mm width (0.03°) on a white background (100 cd/m^2). The experimental paradigm was shown in Figure 13b, with a visual stimulus appeared at the center of the screen, above a 7-point-Likert scale.

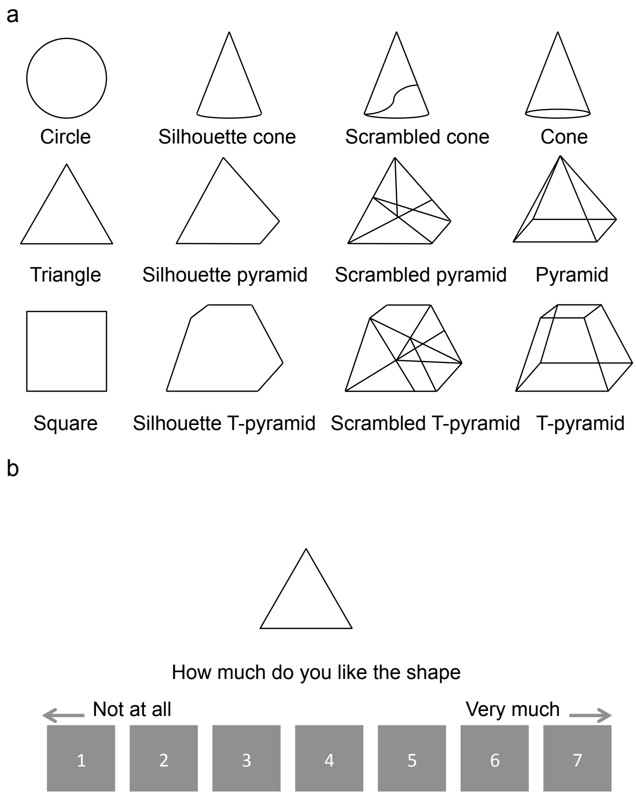


Figure 13. (a) Visual stimuli of shapes (0° rotation), (b) An example of shape preference task. Modified from Figure 1 of Chen et al. (in revised). Copyright by the authors. Reprinted with permission.

Procedure

The experiment was carried out in a laboratory with dimmed lighting (1 lux measured on the wall of the laboratory). Participants were seated in front of a computer monitor and instructed to rate how much they liked each of colors and shapes, using a 7-point Likert scale (from “1” denoting “most disliked” to “7” denoting “most liked”). Colors and shapes were rated in two separate sessions. Participants responded by mouse click on a numeric square labeled from one to seven. After the response, the next trial started immediately.

5.2.2 Results and Discussion

Preference for colors and shapes

In order to facilitate analysis and interpretation, the 40 colors were grouped into eight categories as the previous studies have done. A one-way ANOVA on the average liking ratings of the 8 color groups revealed a significant main effect of color group ($F(7, 136) = 8.91$, $p < .01$). Post-hoc multiple pairwise comparisons showed that our participants preferred color GY least (i.e., green-yellow; Bonferroni correction, $p < .05$; Fig.14).

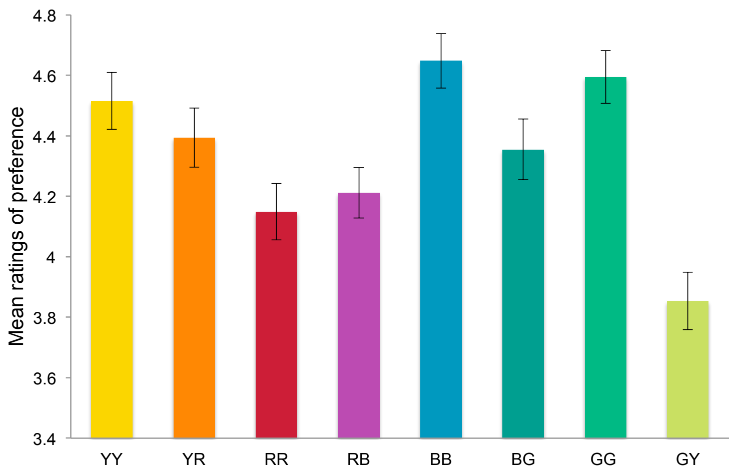


Figure 14. Liking ratings for color groups. Means are calculated for trials of 137 participants. Error bars represent the standard errors of the mean. Modified from Figure 2 of Chen et al. (in revised). Copyright by the authors. Reprinted with permission.

A one-way ANOVA on the liking ratings of all 40 colors revealed significant differences ($F(39, 136) = 8.79$, $p < .01$). Post-hoc multiple pairwise comparisons showed that colors No.19-23 (i.e., blue colors), and No.35 (i.e., a green color) were rated as the most liked colors, while colors No. 16-18 (i.e., purple colors) and No.38-40 (i.e., green-yellow colors) were less liked (Ryan's method, $p < .05$). Thus our participants tended to prefer blue colors to green-yellow colors, consistent with previous findings (Palmer & Scholoss, 2011).

A one-way ANOVA on the average liking ratings for all 12 shapes showed significant main effects of shape ($F(11, 136) = 45.37$, $p < .01$). Our participants preferred the basic geometric shapes (i.e., circle, triangle, and squares) and 3D shapes (i.e., cone, pyramid, and truncated-pyramid) to the created novel shapes (silhouette pyramid, scrambled pyramid, silhouette truncated-pyramid, and scrambled truncated-pyramid). In particular, the circle was the most liked of all the shapes (Post-hoc multiple pairwise comparisons, Bonferroni correction, $p < .05$; Fig. 15).

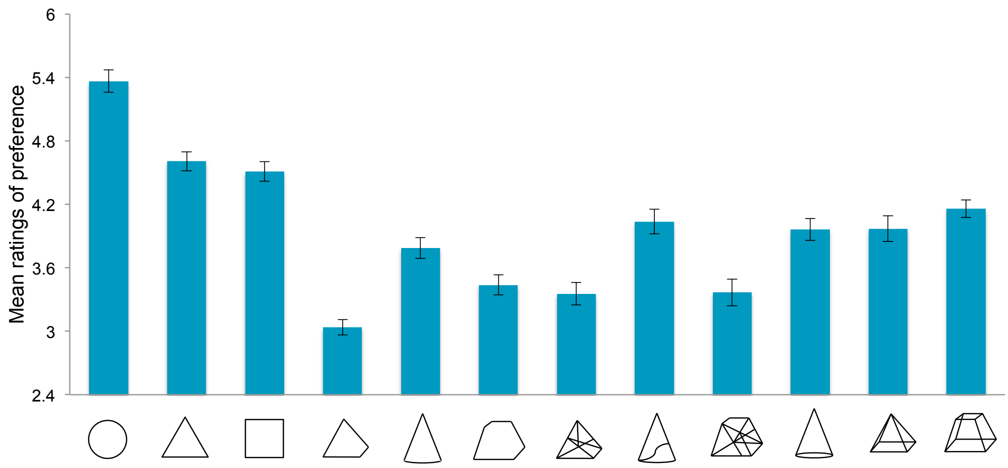


Figure 15. Liking ratings for shapes. Means are calculated for trials of 137 participants. Error bars represent the standard errors of the mean. Modified from Figure 3 of Chen et al. (in revised). Copyright by the authors. Reprinted with permission.

For the next analysis, I compared the liking ratings of the three 3D shapes (i.e., cone, pyramid, and truncated pyramid), the silhouette of 3D shapes (i.e., cone silhouette, pyramid silhouette, truncated-pyramid silhouette), and the scrambled 3D shapes (i.e., scrambled cone, scrambled pyramid, scrambled truncated-pyramid). Shape preferences were further examined in terms of 1) three basic shapes (i.e., cone, pyramid, and truncated-pyramid), 2) three levels of shape structure (i.e., silhouette of 3D shapes, normal 3D shapes, and scrambled 3D shapes), 3) three levels of shape size (i.e., large, medium, and small), and 4) three levels of shape rotation (i.e., 0°, 15°, and 345°). A four-way ANOVA (3 shapes × 3 structures × 3 sizes × 3 rotations) was performed on the liking ratings of the shapes (see Table 9).

Results showed significant main effects of shape ($F(2, 136) = 114.85$, $p < .01$), structural level ($F(2,272) = 93.57$, $p < .01$), size ($F(2, 272) = 9.09$, $p < .01$), and rotation ($F(2, 272) = 15.29$, $p < .01$). There were also significant interactions between preference for shape and structure ($F(4, 544) = 30.43$, $p < .01$), shape and size ($F(4, 544) = 3.61$, $p < .01$), and structure and size ($F(4, 544) = 5.22$, $p < .01$).

Regarding 1) the three basic shapes, post-hoc multiple comparisons with Ryan's method showed that people liked the cone and cone-based novel shapes most (shapes created based on cones, mean rating = 4.29, *SD* = 0.82), secondly the pyramid and pyramid-based novel shapes (shapes created based on pyramid, mean rating = 3.45, *SD* = 0.64), and the truncated-pyramid, and that based novel shapes least (shapes created based on truncated-pyramid, mean rating = 3.29, *SD* = 0.74; *p*s < .05). Regarding 2) structural levels, multiple comparisons with Ryan's method showed that normal 3D shapes (mean rating = 3.83, *SD* = 0.59) tended to be preferred to the silhouette of 3D shapes (mean rating = 3.42, *SD* = 0.65) and scrambled 3D shapes (mean rating = 3.63, *SD* = 0.62; *p*s < .05). Regarding 3) size, multiple comparisons with Ryan's method showed that larger shapes (mean rating = 3.78, *SD* = 0.59) and medium shapes (mean rating = 3.68, *SD* = 0.51) were liked more than small shapes (mean rating = 3.57, *SD* = 0.77; *p*s < .05). Regarding 4) rotation, post-hoc multiple comparisons with Ryan's method showed that neutral shapes (mean rating = 3.75, *SD* = 0.59) were preferred to left (mean rating = 3.61, *SD* = 0.59) and right rotated shapes (mean rating = 3.66, *SD* = 0.56; *p*s < .05).

Regarding the interactions between liking ratings for shape and structural levels, multiple comparisons with Ryan's method showed that the participants tended to like the cone than the pyramid and the truncated-pyramid across all the three structural levels (*p*s < .05).

Participants also tended to like the normal shape than the silhouette, and the scrambled form of all the three 3D shapes (*p*s < .05). Regarding the interactions between liking ratings for shape and size, multiple comparison using Ryan's method suggested that our participants tended to like cones more than the other two shapes across the three different sizes (*p*s < .05); besides, the larger shapes were more preferred across the three shapes (*p*s < .05). Regarding the interactions between structural levels and sizes, multiple comparisons with Ryan's method suggested that participants tended to like the large size to the small and middle sizes in all different structural levels (*p*s < .05); besides, for the normal shapes, participants tended to like the larger than smaller sizes (*p*s < .05).

Table 9. Results of 4-way ANOVA for shape preference

Subject	SS	*df*	MS	F	*p* value
Shape (A)	2153.97	2	1076.98	114.85	< .01
Structure (B)	2907.66	2	1453.83	93.57	< .01
Size (C)	78.28	2	39.14	9.09	< .01
Rotation (D)	32.87	2	16.44	15.29	< .01
A × B	475.46	4	118.87	30.43	< .01
A × C	9.69	4	2.42	3.61	< .01
A × D	0.19	4	0.05	0.07	.99
B × C	18.07	4	4.52	5.22	< .01
B × D	4.66	4	1.17	1.69	.15
C × D	2.94	4	0.73	1.20	.31
A × B × C	5.77	8	0.72	1.00	.44
A × B × D	3.96	8	0.49	0.78	.62
A × C × D	2.57	8	0.32	0.56	.82
B × C × D	6.54	8	0.82	1.37	.21
A × B × C × D	8.00	16	0.50	0.78	.71
Error	1399.75	2176	0.64		
Total	25569.21	11096			

Taken together, those results indicated that participants tended to like the cones and cone-based novel shapes than the pyramid and pyramid-based novel shapes, than the truncated pyramid and truncated-pyramid-based novel shapes. As cones and cone-based shapes contain curved-line, it might suggest that people tend to like curved-line shapes than straight-line shapes. Furthermore, our participants also tended to prefer the familiar normal 3D shapes to the created shapes based on those shapes (the silhouette of 3D shapes and scrambled 3D shapes), which may suggest that familiar shapes tend to be preferred. Moreover, our participants tended to prefer larger shapes to smaller shapes, and shapes with no rotations to rotated shapes. These results were in line with the fluency theory, that people tend to prefer visual stimulus to the extent they are easily or fluently processed (Palmer, Schloss, & Sammartino, 2013; Silvera, Josephs, & Giesler, 2002; Reber, Schwarz, & Winkielman, 2004; Bryson & Driver, 1972; Reber, Winkielman, & Schwarz, 1998).

Correlations between preferences for colors and shapes

In order to clarify the relationships between color and shape preferences, I used the Q-mode factor analysis to identify the structure of these preferences, and the correlations between them. Q-mode analysis is a sample-based factor analysis. It differs from conventional factor analysis in that the data are transposed, such that correlations are computed between the participants but not between the stimuli. Thus, it provides an ideal tool for examining relationships among individuals (McManus, Cook, & Hunt, 2010; McManus & Wu, 2013; McManus, Jones, & Cottrell, 1981).

In the present study, the preferences of a given participants for colors and shapes were correlated with those of other participants. Thus, the similarity or the dissimilarity between individual preference judgments for colors and shapes (i.e., positive or negative correlations) were measured and used to construct the compositions of participants. The Q-mode factor analyses of the liking ratings made by 137 participants were conducted separately for the 8 color groups and 12 shape groups. The extraction method used principal components analysis followed by a Promax rotation, suggesting several main factors in each analysis.

The Q-mode factor analysis of the liking ratings for 8 color groups and 12 shape groups from 137 participants were conducted separately. Extraction used principal components analysis followed by a Promax rotation suggested several main factors in each case. Here, I extracted factors that explained more than 15% of the total variance.

For individual color preferences, the three factors accounting for 68.63% (31.12%, 20.36%, and 17.14% for first, second, and third factor, respectively) of the total variance were extracted. The three factor scores were computed by multiplying each element of the participant's preference by loading on each of the factors, and summing across all participants. Figure 16 shows the three factors for color preferences. The first factor (C1) denotes a strong preference for the colors BG, BB, and GG, and negative affect toward colors YY, YR, and RR, which essentially describes a preference for cold but not warm colors. Factor C2 shows a peak liking at the colors BB and RB, and dislike for GY. Factor C3 denotes peak preferences for colors YR and YY, and a minimum preference for colors RB, RR, and BB, which may denote a preference for light over dark colors.

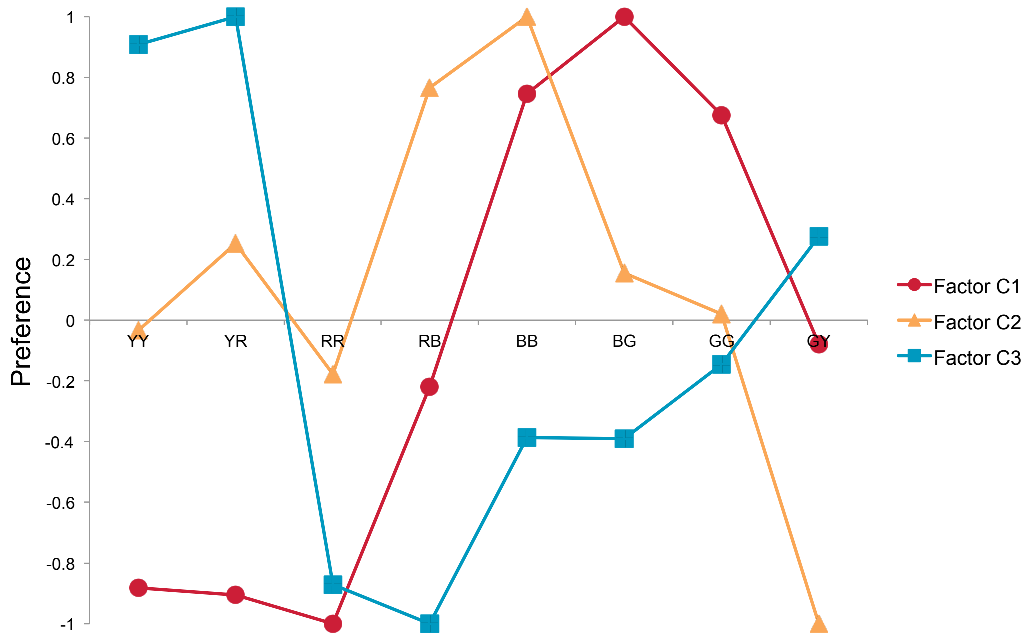


Figure 16. Color preference functions for the three factors. The functions were calculated from the color preference functions of 137 participants, weighted by their loadings on the Q-mode factors, and then arbitrarily scaled from -1 to 1. Modified from Figure 4 of Chen et al. (in revised). Copyright by the authors. Reprinted with permission.

For individual shape preferences, I extracted two factors accounting for 62.31% of the total variance (40.96% and 21.35% for the first and second factor, respectively). Figure 17 shows the two factors pertaining to the shape preferences. We can see that both the two factors show a peak preference for the circle, triangle, and square. This might indicate that preferences for the normal 2D shapes have no individual differences. Except for these three basic shapes, the first factor (S1) shows peaks in preference for some simple, sharp angular shapes, such as the cone, cone silhouette, and pyramid, and less preferences for some complex shapes, such as the scrambled truncated-pyramid, scrambled pyramid, and truncated-pyramid silhouette. Thus factor S1 may essentially be a preference for simple but not complex shapes. The second factor (S2) shows preferences for the truncated-pyramid, scrambled truncated-pyramid, and truncated-pyramid silhouette, and low preference for the pyramid silhouette, cone silhouette, and cone. Thus factor S2 may represent a preference for squared blunt or complex shapes to sharp or simple shapes.

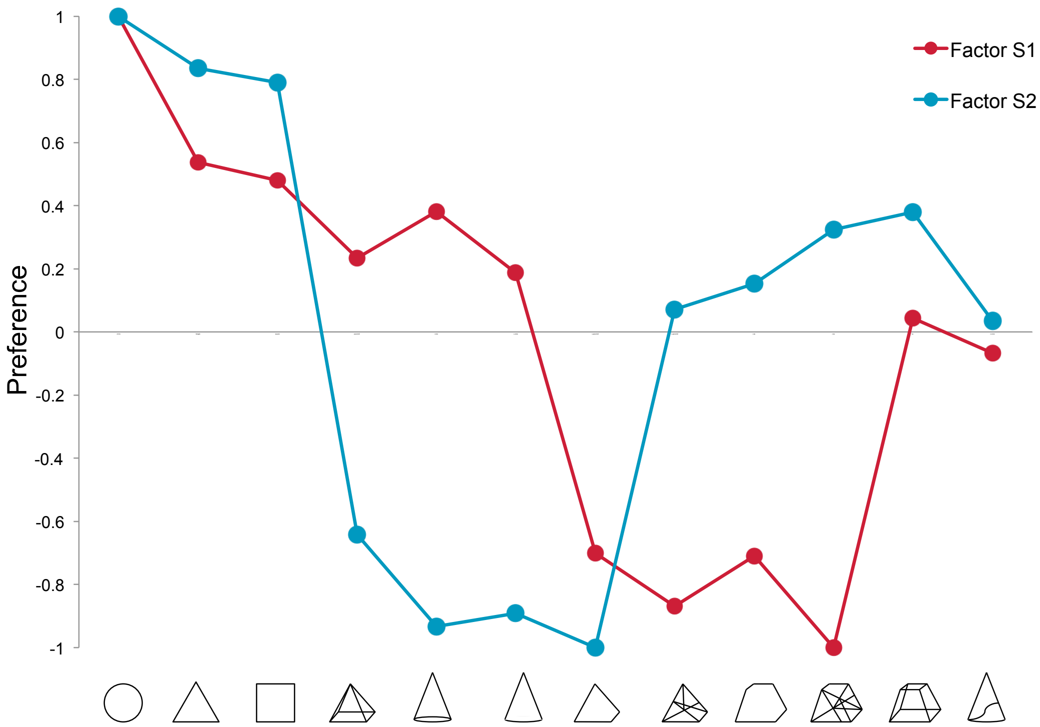


Figure 17. Shape preference functions for factor S1 and factor S2. The functions were calculated from the preference functions of 137 participants, weighted by their loadings on the Q-mode factors, and then arbitrarily scaled from -1 to 1. Modified from Figure 5 of Chen et al. (in revised). Copyright by the authors. Reprinted with permission.

From the Q-mode factor analysis of color and shape preferences, several main groups of individuals who have specific color and shape preferences were verified. For example, the present set of participants could be mainly characterized with individuals who prefer warm colors versus cold colors, or who prefer simple shapes versus complex shapes. The main interest here was possible cross-preferences for colors and shapes from an individual differences perspective, i.e., that individuals who prefer certain colors might also tend to prefer certain shapes. Therefore, a correlation analysis was used to examine the possible correlations between individual color and shape preferences. Since the three factor scores for color preferences and the two factor scores for shape preferences all followed a normal distribution, Pearson's correlation coefficients were used to represent the correlations between factor scores for color preference and shape preference. A significant correlation was observed between factor S1 of shape preference and factor C3 of color preference, and the coefficient between factor S1 and factor C2 approached significance. Factor S1 indicates a preference for simple but not complex shapes, and factor C3 represents a preference for light but not dark colors; therefore, the positive correlation between factors S1 and C3 suggests that individuals who prefer simple shapes also tend to prefer light colors. Conversely, individuals who prefer complex shapes tend to prefer dark colors. The semantic information expressed by colors and shapes, such as simple versus complex, or light versus dark, might account for the relationships between color preference and shape preference, i.e., that some individuals prefer simple or light visual features, while other individuals tend to prefer complex or dark visual features.

Table 10. Correlation matrix between factors of color preference and shape preference

		Shape preference	
		Factor S1 (Simple)	Factor S2 (dull)
Color preference	Factor C1 (BG)	-0.035	-0.017
	Factor C2 (BB)	-0.122 $^{+}$	0.024
	Factor C3 (YY)	0.148 *	-0.022

Note: N = 137; "*" $p < .05$; "+" $p < .1$

In order to further verify this cross preference, the Q-mode factor analysis was conducted on the liking ratings of colors and shapes together from each individual. I extracted two factors accounting for 43.75% of the total variance (29.23% and 14.52% of variance, respectively). I interpreted the results as follows: Figure 18 shows the two factors for the individual preference functions of colors and shapes. Factor P1 shows individual preferences for some simple shapes and some light or warm colors. Factor P2 shows individual preferences for some complex shapes and some dark or cold colors. Therefore, our participants might contain two groups, one of which consists of individuals who prefer simple shapes and light or warm colors, and the other of individuals who prefer complex shapes and dark or cold colors. This further demonstrates that individual preferences for colors and shapes can be intertwined; people who prefer certain colors (shapes) also tend to prefer specific shapes (colors).

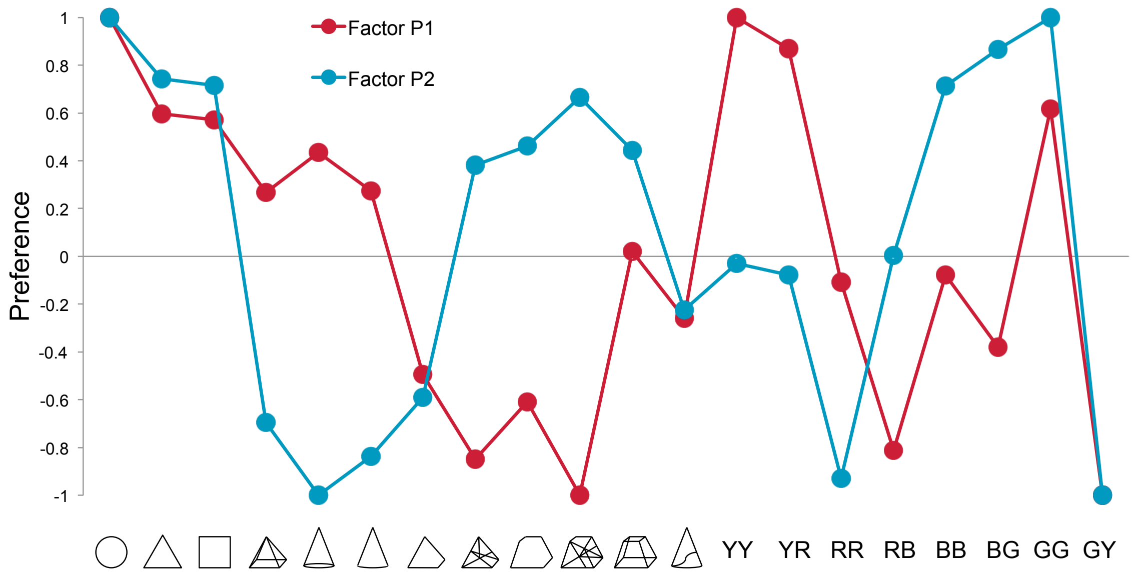


Figure 18. Individual preference functions for colors and shapes with Factor P1 and Factor P2. The functions were calculated from the preference for colors and shapes of 137 participants, weighted by their loadings on the Q-mode factors, and then arbitrarily scaled from -1 to 1. Modified from Figure 6 of Chen et al. (in revised). Copyright by the authors. Reprinted with permission.

5.3 Discussion

Experiment 6 investigated the relationships between preferences for colors and geometric shapes, from an individual differences perspective. Individual color and shape preferences were correlated to some extent; individuals who preferred certain simple shapes (i.e., cone, cone silhouette) tended to prefer specific light or warm colors (e.g., YY or YR), while individuals who prefer certain complex shapes (e.g., scrambled truncated-pyramid, scrambled pyramid) tended to prefer specific dark or cold colors (e.g., BB or BG).

Color preferences

Participants tended to prefer blue, and to prefer green-yellow colors less. This result is consistent with previous reports. The basis of this finding might be related to the positive semantic image (e.g., calm and clean) associated with blue and the negative image (e.g., sickness or immaturity) associated with green-yellow. Individual difference for color preference suggested three factors to describe the present samples, such that participants who tend to prefer warm to cold colors, or participants who tend to prefer light to dark colors (Palmer & Schloss, 2010; Ou, Luo, Woodcook, & Wright, 2004; Kaya & Epps, 2004).

Shape preferences

Some shapes were preferred to others. For example, the simple shapes were preferred to the complex shapes, larger shapes were preferred to smaller ones, and curved-line shapes were preferred to straight-line shapes. These results are consistent with previous findings that people tend to prefer simple, curved, prototypical, and symmetrical shapes (Silvera, Josephs, & Giesler, 2002; Reber, Schwarz, & Winkielman, 2004). Shape preferences could also be explained by the positive semantic information those shape features convey (Bar & Neta, 2006; Davis & Jahnke, 1991; Jacobson & Hofel, 2002; Silvia & Barona, 2009; Hunt & Agnoli, 1991; Tonio & Leder, 2009). For example, preference for curved-line shapes to sharp shapes might be due to the semantic information the shapes conveyed, that curved-line shapes indicate positive semantic information, while sharp shapes may suggest dangerous. Shape preference on Q-mode factor analysis suggested two factors to underline the individual difference, that individuals who tend to prefer simple shapes and individuals who tend to prefer complex or dull shapes.

Cross-preferences between colors and shapes

Q-mode factor analysis on preferences for colors and shapes suggested several main factors that accounted for much of the individual differences in each case. Significant correlations were found between factor S2 of shape preference and factor C3 of color preference. This suggests that individuals who preferred specific simple shapes (e.g., cone, silhouette cone, pyramid) tended to prefer certain light colors (e.g., YY, YR), and individuals who preferred specific complex shapes (e.g., scrambled truncated-pyramid, scrambled pyramid) tended to prefer certain dark colors (e.g., RB, BB, RR). Further individual preferences for the visual stimuli as a whole suggested two main factors. Factor 1 suggested a preference for simple shapes and light or warm colors, and factor 2 suggested a preference for complex shapes and dark or cold colors. These results verify that individual preferences for colors and shapes intertwine or correlate to some extent. People who prefer certain colors tend to prefer specific shapes, and these cross-preferences might be explained by individual predilections for particular semantic information conveyed by visual colors and shapes, such as concepts of simple versus complex, and light versus dark. The semantic information conveyed by "simple" and "light" might be associated, as might be the semantic content of "complex" and "dark." The associated semantic information might play a role in determining the cross-preferences for colors and shapes. That is, some individuals may like "simple" and "light" visual features, while the others like "complex" and "dark" visual features.

The present results show that preferences for multiple visual cues, such as colors and shapes, are not independent within individuals; instead, these preferences can be related through similar or associated semantic information. Studies have reported that simple, low-order features of geometric shapes and colors are implicitly associated with affective values and semantic impressions, and some of those semantic impressions could be connected or associated among multiple visual stimuli, such as colors and shapes (Ou, Luo, Woodcook, & Wright, 2004; Watson, Blagrove, Evans, & Moore, 2012; Larson, Aronoff, & Steuer, 2012). These results support that high-order preferences can be influenced by the semantic information associated with low-level visual features.

Summary

In this chapter, the relationship between preferences for colors and shapes was investigated. The results showed there exist some cross-preferences for colors and geometric shapes, i.e., that individuals who prefer specific colors/shapes tend to prefer specific shapes/colors. The basis of these associations may lie in similar or associated semantic information linked to colors and shapes. This is the first study to integrate basic color preferences and geometric shape preferences to examine the relationship between them from an inter-individual differences perspective. The results are consistent with the contention that common or associated semantic information might lead to intertwined preferences for colors and shapes. This might be helpful in tailoring product design in relation to individual preferences.

6. General Discussion

The goal of the experiments described here was to determine the general associations between colors and shapes. The results may be summarized as follows: In the first study (chapter 2), I found that (1) Japanese people produced systematic color-shape associations using an explicit matching task, which were consistent with Italian participants. For example, people from both cultures tended to match red with circles and yellow with triangles. (2) Common semantic information might lead to these color-shape associations, such as the perception of colors and shapes as being "warm" or "cold". Thus people tended to associate "warm/cold" colors with "warm/cold" shapes. In the second study (chapter 3), I adopted an indirect behavioral method, i.e., the implicit association tests (IATs) to examine whether color-shape associations could be proved by indirect behavioral method. (3) The implicit association tests showed limited evidence for Kandinsky's color-shape associations. (4) Findings from Experiment 1 concerning Japanese people's color-shape associations were refined by the implicit association tests. Japanese people's color-shape associations could be assessed using this indirect, behavioral performance method, and the paradigm indicated that the color-shape associations robustly influence visual target discrimination and associated response times. Thus, Japanese color-shape associations could be measured using both direct and indirect experimental methods. In the third study (chapter 4), I examined the effect of sounds on color-shape associations by assessing the performance of deaf individuals on direct questionnaire survey and indirect implicit association tests, and compared with that of people with normal hearing. (5) Deaf people showed similar color-shape associations with hearing people in the direct questionnaire survey. (6) Deaf people revealed limited and weak congruency effect of color-shape associations compared with hearing people in the indirect

IAT tasks. Therefore, the sound or hearing experience plays a role in visual color-shape associations. In the last study (chapter 5), I investigated the cross-preferences between colors and shapes. (6) Preferences for colors and shapes were intertwined to some extent. People who preferred certain colors tended to prefer specific shapes. Based on these results, I suggested that semantic sensory correspondence could account for color-shape associations.

Studies have reported that neurotypical individuals show some crossmodal correspondences, such that our brain tends to match distinct features or dimensions of experience across different sensory modalities (Spence, 2011). For example, people tend to match high-pitched sounds with high spatial locations, bright colors, sharp angular shapes, small sizes, and lightweights as compared with low-pitched sounds (Collier & Hubbard, 2001; Ben-Artzi & Marks, 1995; Eitan & Timmers, 2010; Martino & Marks, 1999; Spence, 2011). Spence (2011) suggested that there are at least three qualitatively different kinds of crossmodal correspondence: statistical, structural, and semantically mediated correspondences, which have different developmental trajectories and consequences for human perception and behavior. Structural correspondences may occur because of neural connections that are present at birth, reflecting a common basis for coding stimuli that share features such as magnitude or intensity, such as when the neural system codes information from different sensory channels in adjacent brain areas or in similar ways (e.g., correspondences between loudness and brightness). Statistical correspondences are acquired through perceptual learning following repeated exposure to co-occurrences in the natural environment. For example, we match smaller objects with lighter weights, and smaller objects tend to resonate faster than larger ones. Semantically mediated correspondences stem from the use of common lexical terms to describe stimuli in different sensory channels (e.g., the words “high” and “low” mark contrasting levels of pitch, spatial elevation, and spatial frequency, which leads to the correspondences among them). Martino and Marks (1999) suggested a semantic coding hypothesis to interpret the crossmodal correspondences that emerged only after language acquisition (Marks, 1984; Marks et al., 1987; Smith & Sera, 1992). They posited that such correspondences arise from coding perceptual stimuli into semantic representations, reflecting interactions between linguistic and semantic meanings. Therefore, the semantically mediated correspondences operate at later conceptual, rather than perceptual, stage of information processing.

This thesis on intra-modal correspondences between colors and shapes might provide support for the third class of crossmodal correspondence, i.e., semantically mediated correspondences. Using directly semantic rating tasks to assess semantic information for both colors and shapes, and correlating those ratings with the associations between colors and shapes showed strong evidence that "warm/cold" semantic information for colors and shapes could interpret most of those color-shape associations observed in the present study. Thus, I proposed that color-shape associations could be explained by semantic sensory correspondence between colors and shapes (e.g., warm/cold). These correspondences suggest that information from different sensory modalities is encoded into a common semantic basis; attributes that fall toward the same pole of a given semantic dimension tend to be matched. Semantic bases are universal to all sensory channels. If crossmodal correspondences derive from a semantic basis, they can occur among any sensory channels, within or across modalities. Thus, the intra-visual color-shape associations provide direct evidence for semantic sensory correspondences.

According to semantic sensory correspondences, when participants were asked to choose which color best matched a shape in the explicit matching tasks, sensory information from shape and color stimuli converged into a common, abstract, semantic representation. The common or associated semantic information was automatically encoded, and divided the sensory experience into a bipolar dimension (e.g., "warm/cold"). Then, colors and shapes with equivalent semantic information, which were located toward the same pole of the bipolar dimension, tended to be associated.

Furthermore, if color-shape associations were encoded, it should be measured by indirect behavioral method, such that people may not show some color-shape assignment when directly inquired, but should indicate the preference if tested indirectly. In chapter 3, I used an indirect experimental method by the implicit association tests, which indirectly examine people's color-shape associations and require participants to respond as quickly as possible. Results showed that response times were significantly faster when red-circle, blue-square, and yellow-triangle combinations were mapped onto the same response key, indicating that these color-shape combinations were encoded and could be proved using behavioral performance method. The color-shape associations were stable and robust so that they influenced the perceptual discrimination of colors and shapes and consequently, task performance.

During the implicit association test, participants were asked to discriminate a color or shape by pressing a key. When the color and shape assigned to the same response key were associated (congruent condition), the response times were shorter than when the color and shape were not associated (incongruent condition). This result can be interpreted by reference to semantic sensory correspondences. Colors and shapes were encoded and converged into a semantic representation. According to our brain tend to process information efficiently that arrives from multiple senses at the same time, the response time to discriminate color or shape stimulus which were at the same pole of certain semantic and associated should be faster. Thus, when asked to discriminate a color/shape stimulus by key press, color-shape combinations with the same or common semantic information produced a compatible effect in response times.

In particularly, deaf people also showed specific color-shape associations, which was consist with hearing people in the explicit questionnaire survey. However, deaf people's color-shape associations failed to produce any compatible effect on response times in the IAT tasks, which was different from that of hearing people. Therefore, hearing experience influence color-shape associations to some extent. According to the semantic coding hypothesis, perceptual information incorporated into language with time and experience, correspondence might occur when perceptual information encoded into a common semantic basis. With limited hearing experience, deaf people's language development might have a different trajectory compared with hearing people. The language impairment might also lead to weaker perceptual/cognition task performance compared with hearing people, which might influence the compatible effect of color-shape association on response time in the indirect behavioral task. Therefore, the lacking of sounds or hearing experience influencing language development affects the strength of color-shape associations, which could not be verified using indirect behavioral method. In addition, hearing experience might play a limited role in the long-term learning language experience involved in encoding perceptual information into a semantic format. Moreover, short-term visual perceptual information processing and response selection for stimulus discrimination, which requires the rapid coding of these percepts into semantics in a relatively short time, is notably affected.

In the final part of this research, I further tested whether semantic information also mediated the relationships between preference dimensions for colors and shapes. Cross-preferences between colors and shapes suggested that people who preferred some simple/complex shapes also tended to prefer light/warm colors. Thus, preferences for colors and shapes are not independent, and they may correlate with each other through some associated semantic content.

The human brain combines information input from multiple sensory modalities, and generates a unified perceptual world. However, how the brain combines information from these crossmodal interactions and integrations remains largely unknown. Semantic sensory correspondences between colors and shapes might help us to understand the nature of crossmodal correspondences, and shed light on crossmodal binding problems.

The findings of the present study have relevance not only in understanding the mechanisms of crossmodal correspondences, but also in the other fields of study. For example, I reported that people tended to respond faster when circle and red were assigned to the same response key rather than other key combinations, which indicates some implicit associations between circle and red. It might be used in the product package design, which might be more easily to search and pick up on a shelf. In addition, I also observed that people who prefer circles tend to prefer red. Both crossmodal correspondences and preferences provide information of relevance to industrial product design and advertisement. I also reported that sound influences color-shape associations. People's visual experiences might altered by combined them with sounds, which will potentially be beneficial to marketing and industry.

In conclusion, the results of the present series of studies demonstrate that the color-shape associations can be interpreted as semantic sensory correspondence between colors and shapes, which provide insights into one aspect of crossmodal binding.

7. Appendix

- Explicit questionnaire survey A— Explicit matching task

性別：　　　　年齢：

左側に示されている図形と最も合うと思う色を，右側に示されている４色から１色だけ選んでください。
色の近くに✓をしてください。

(1)

(2)

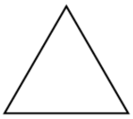
(3)

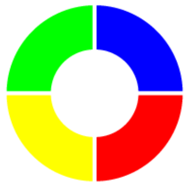
- Explicit questionnaire survey B— Confidence rating task

性別：　　　　年齢：

今，あなたが回答した色と形の組み合わせについての質問です。
あなたと同年代の人に対して同じ質問をしたときに，
あなたと同じ回答をするかどうかについての自信度を回答してください。

(1)

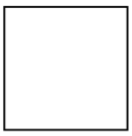




あなたと同年代の人も，あなたと同じ回答をすると思いますか？

絶対にしないと思う　しないと思う　不確かである　すると思う　絶対にすると思う

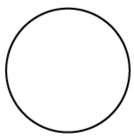
(2)

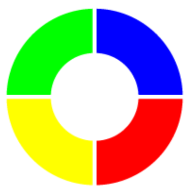


あなたと同年代の人も，あなたと同じ回答をすると思いますか？

絶対にしないと思う　しないと思う　不確かである　すると思う　絶対にすると思う

(3)





あなたと同年代の人も，あなたと同じ回答をすると思いますか？

絶対にしないと思う　しないと思う　不確かである　すると思う　絶対にすると思う

ご協力ありがとうございました

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