What regulates the surface color effect in object recognition: Color diagnosticity or category?

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The effect of surface color on object recognition has been controversial. Tanaka and Presnell (1999) claimed that the degree to which an object is associated with a specific color, or *color diagnosticity* is crucial: Surface color plays a major role in recognition of high color diagnostic (HCD) objects (e.g., banana), but not in that of low color diagnostic (LCD) objects (e.g., sports car). On the other hand, past results also suggest that color is beneficial in recognition of natural objects (e.g., fruit and vegetables) more than man-made objects (e.g., tools and furniture). The present study examined the relation between the surface color effect, color diagnosticity, and object category. In a classification experiment, the surface color effect was observed only in HCD objects regardless of their category, supporting the color diagnosticity hypothesis of Tanaka and Presnell (1999). Moreover, there was no difference in response time between HCD and LCD man-made objects, whereas HCD natural objects were classified faster than LCD natural objects. The interaction between category and color diagnosticity requires future examination.

Keywords: object recognition, surface characteristics, color diagnosticity, category

Introduction

The effect of surface color on object recognition has been examined by many researchers. In their pioneering work, Biederman and Ju (1988) investigated whether there were differences in response time for object recognition between color photographs and line drawings. In their study, a panel of three judges decided whether or not color was representative of each of 29 objects (25 man-made and 4 natural objects). The results of five experiments showed that the presence of surface color had no systematic effect on object recognition regardless of whether color was representative of the objects. Therefore, Biederman and Ju (1988) concluded that color does not play a major role in object recognition, independent of how an object is associated with a specific color, or "*color diagnosticity*."

Regarding the measure of color diagnosticity, however, Tanaka and Presnell (1999) made the point that the methodology by Biederman and Ju (1988) was based on merely color representativeness, or typicality. Instead, Tanaka and Presnell (1999) claimed that color diagnosticity should be determined by both feature listing and typicality judgments. In their study, subjects were asked to list three perceptual features of each object and to mention its typical color. Then the objects were ranked according to the ratio of subjects who listed a color as the first feature. If the ratio was high and the same color was mentioned as typical color by most of the subjects, the object was determined as high color diagnostic (HCD) object. The object for which a color was rarely or never listed as the first feature was determined as low color diagnostic (LCD) object. In the following object recognition experiments, Tanaka and Presnell (1999) demonstrated that surface color facilitated the recognition of HCD objects, but there was no effect of color on the recognition of LCD objects. Tanaka and Presnell suggested that according to their criteria, many of Biederman and Ju's (1988) stimuli were not HCD objects, so they failed to obtain the effect of surface color.

On the other hand, the effect of surface color obtained in past studies can be interpreted in connection with object category. In cases in which surface color facilitated object recognition (e.g., Price & Humphreys, 1989; Wurm, Legge, Isenberg, & Luebker, 1993), most of the stimuli belonged to natural categories (e.g., fruit and vegetables). By contrast, the stimuli used by Biederman and Ju (1988), in which the surface color effect was not observed, were mostly man-made objects (e.g., tools and furniture). Other studies (Humphrey, Goodale, Jakobson, & Servos, 1994; Nagai & Yokosawa, 2003) have shown similar trends. Actually, in Tanaka and Presnell's (1999) study, most of the HCD objects were natural objects and most of the LCD objects were man-made objects. As Tanaka and Presnell stated, there remains the possibility that the human visual system uses more color information for recognition of natural objects than man-made objects, because objects from natural categories tend to have less distinctive structural properties and more distinctive color properties.

The purpose of the present study was to investigate which is the regulatory factor of the surface color effect, color diagnosticity or category. Following the same methodology as Tanaka and Presnell (1999), HCD and LCD objects were determined from natural and man-made categories, respectively (Experiment 1). Then, an object recognition experiment was conducted in which the participants classified colored and achromatic versions of these objects (Experiment 2). The main finding was that the presence of surface color facilitated the recognition of HCD objects but it did not affect the recognition of LCD objects, irrespective of whether the objects belonged to man-made or natural categories.

Experiment 1: Feature Listing and Typicality Judgments

Using the feature-listing and typicality-judging method (Tanaka & Presnell, 1999), HCD and LCD objects were determined and selected from each of man-made and natural categories.

Method

Participants. Fifty-four native Japanese students of Meiji Gakuin University were tested in groups. All the participants reported normal or corrected-to-normal visual acuity and normal color vision. The participants received class credit for their participation.

Materials. Seventy-four object names (34 from man-made categories and 40 from natural categories) were selected for the feature-listing task. They are listed in Appendix A (They were actually presented in Japanese). All of the names were basic or entry level words in Japanese. The names were printed individually at the top of sheets of paper (13 x 18 cm) and bound into booklets in pseudo-random order.

Procedure. The experiment consisted of two stages. In the first stage, the participants were given the booklet and instructed that they would be given 10 sec to list three perceptual features of each object. In the second stage, the participants were instructed that they would be given 10 sec to mention the typical color for each object.

Results and Discussion

For each of the objects, the ratio of participants who agreed on its typical color in the second stage and the ratio of participants who mentioned the typical color as its first feature in the first stage were calculated respectively (see Appendix A). Color diagnosticity was determined on the basis of these two values. If the percentage of the typicality agreement was more than 70% and that of the first mention was more than 35%, such an object was determined as HCD object. If the former was more than 70% and the latter was under 35%, such an object was determined as LCD object. According to these criteria, 7 HCD and 7 LCD objects were selected from each of man-made and natural categories (see Table 1) and used in Experiment 2. Because it was needed to select the same number of HCD and LCD objects from respective categories, the baseline of high diagnosticity (35%) was quite lower than that of Tanaka and Presnell (80%) necessarily.

Table 1. High and low color diagnostic objects from man-made and natural categories, based on the percentage of subjects who listed the object's typical color (in parentheses) first in feature listing.

Man-made			Natural		
Objects	% Listed First	(Typical color)	Objects	% Listed First	(Typical color)
High Color Diagnostic (HCD)					
Fire engine	80	(red)	Crow	89	(black)
Ambulance	50	(white)	Pimento	85	(green)
Piano	43	(black)	Tomato	82	(red)
Trumpet	41	(gold)	Banana	82	(yellow)
Eraser	37	(white)	Strawberry	76	(red)
Shirt	37	(white)	Rabbit	50	(white)
Spoon	35	(silver)	Locust	46	(green)
Low Color Diagnostic (LCD)					
Frying pan	19	(black)	Chicken	32	(white)
Desk	11	(brown)	Ant	30	(black)
Dish	9	(white)	Monkey	28	(brown)
Guitar	9	(brown)	Horse	15	(brown)
Socks	9	(white)	Sparrow	11	(brown)
Scissors	7	(silver)	Elephant	9	(grey)
Sports car	7	(red)	Dog	7	(brown)

Experiment 2: Object Classification Task

In Experiment 2, effects of color diagnosticity and category were examined using the object classification task (Tanaka & Presnell, 1999).

Method

Subjects. Seventeen native Japanese students of University of Tokyo (7 women and 10 men, between 18 and 23 years old) were tested individually. All the participants reported normal or corrected-to-normal visual acuity and normal color vision.

Stimuli. Pictures of 56 common objects were used. According to the results of Experiment 1, 28 objects shown in Table 1 were determined as targets objects. Each target object was paired with a foil object on the basis of the following criteria: (1) having distinct color and shape from one another, (2) having similar size, and (3) belonging to the same superordinate category. A list of 28 targets and their respective foils is shown in Appendix B. Each of the 56 objects was presented in two versions: a color version and an achromatic (grayscale) version. The color versions of the objects had their typical color. The achromatic versions were converted from their respective color versions by means of the Adobe Photoshop software.

Apparatus. The stimuli were presented on a 17-inch CRT monitor controlled by an Windows PC. The SuperLab software and a response box (Cedrus RB-610) were used for the experimental control and data collection.

Design. A 2 (category: man-made, natural) x 2 (color diagnosticity: HCD, LCD) x 2 (surface: color, achromatic) within-subjects design was used.

Procedure. Two object names (a target and its foil) were simultaneously presented on the right and left of a display for 2,500 msec, then an object picture was presented on the center of the display. The participants were instructed to decide which of the names, the right or the left, matched the picture and make a key response using their index fingers, as quickly as possible. The picture remained in view until the response. All of the 56 pictures were presented twice in both the color and achromatic versions so there were 224 trials, which were presented in a random order.

Results and Discussion

Mean median response times (RTs) and error rates (ERs) for responding to the target objects are shown in Figure 1. A three-way analysis of variance (ANOVA) conducted on RTs showed a significant interaction between color diagnosticity and surface ($F(1, 16) = 5.34$, $p < .05$). As is shown in Figure 1, RTs for color pictures were faster than achromatic pictures of HCD objects regardless of object category, but there was no systematic difference in RT between color and achromatic pictures of LCD objects. Since there were no significant main effects and interactions in the same ANOVA on ERs, the RT results were not due to a speed-accuracy tradeoff. The results are consistent with the color diagnosticity hypothesis of Tanaka and Presnell (1999). Although the surface color effects obtained in the present study were overall smaller than those in Tanaka and Presnell, this is probably because our HCD baseline was so low (35%) that the effects of color in our HCD objects became inevitably weak.

In the ANOVA on RTs, the main effect of diagnosticity ($F(1, 16) = 4.90$, $p < .05$) and the interaction between category and diagnosticity ($F(1, 16) = 8.18$, $p < .05$) were also significant. Figure 1 shows that there was no RT difference between HCD and LCD man-made objects, whereas RTs for LCD natural objects were slower than HCD natural objects. Because natural objects belonging to the same superordinate category tend to be structurally similar, it may have been very difficult to distinguish LCD natural objects one another due to their lack of surface cues. However, even in the achromatic condition, RT for HCD natural objects was faster than LCD ones. The influence of color diagnosticity on the recognition on natural objects remains a puzzling problem and the clarification is required of future research.

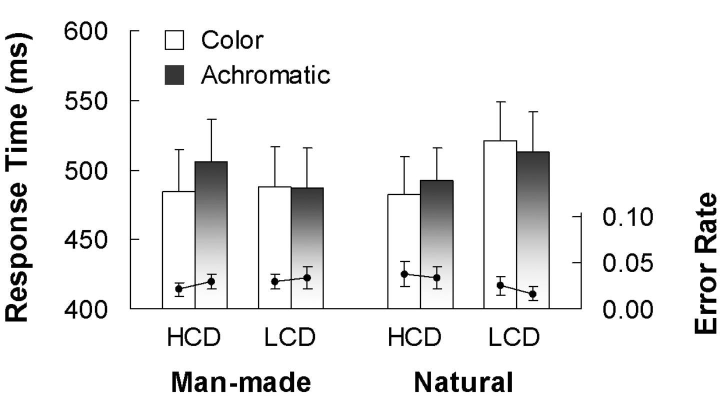

Figure 1. Means of median response times for object classification as a function of category, color diagnosticity, and surface.

Conclusion

Regardless of object category (man-made or natural), the surface color effect (i.e., faster responses to color objects than achromatic objects) was observed in the recognition of HCD objects, but it was not observed in that of LCD objects. The results support the color diagnosticity hypothesis of Tanaka and Presnell (1999).

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Appendix A. Feature Listing Items (Experiment 1)

Man-made				Natural			
Objects	Typical Color	% Agreement	% First Mention	Objects	Typical Color	% Agreement	% First Mention
Fire engine	Red	96	80	Ant	Black	100	30
Ambulance	White	91	50	Apple	Red	98	78
Bandage	White	100	76	Banana	Yellow	100	82
Book	White	59	0	Bee	Yellow	69	6
Bus	White	30	0	Beetle	Black	74	39
Cap	White	32	0	Broccoli	Green	100	78
Chalk	White	94	44	Butterfly	White	43	2
Chopsticks	Brown	56	0	Cat	White	39	0
Desk	Brown	94	11	Cherry blossoms	Pink	98	59
Dish	White	96	9	Chicken	White	96	32
Eraser	White	100	37	Corn	Yellow	100	67
Excavator	Yellow	65	13	Crow	Black	100	89
Flute	Silver	69	15	Dandelion	Yellow	98	67
Fork	Silver	98	24	Dog	Brown	78	7
Frying pan	Black	82	19	Dragonfly	Red	61	4
Glass	Transparent	67	24	Duck	White	89	37
Gloves	White	43	6	Elephant	Gray	98	9
Guitar	Brown	85	9	Fish	Silver	35	0
Hammer	Black	67	7	Fox	Brown	61	15
Neil	Silver	94	17	Frog	Green	100	56
Pen	Black	87	4	Goldfish	Red	82	59
Piano	Black	87	43	Horse	Brown	94	15
Pliers	Silver	59	11	Lemon	Yellow	100	65
Pod	Silver	82	9	Locust	Green	98	46
Scissors	Silver	91	6	Monkey	Brown	98	28
Shirt	White	93	37	Parakeet	Yellow	50	9
Shoes	Black	65	6	Peacock	Green	44	0
Socks	White	76	9	Penguin	Black	67	17
Spoon	Silver	100	35	Pimento	Green	100	85
Sports car	Red	76	6	Rabbit	White	96	50
Truck	Blue	35	0	Rat	Gray	100	44
Trumpet	Gold	89	41	Rose	Red	94	50
Violin	Brown	94	28	Snake	Green	54	2
Wardrobe	Brown	91	2	Sparrow	Brown	98	11
				Strawberry	Red	100	76
				Sunflower	Yellow	100	44
				Tomato	Red	100	82
				Tulip	Red	82	52
				Turnip	White	98	74
				Turtle	Green	89	22

Appendix B. Target and Foil Objects (Experiment 2)

Man-made				Natural			
Target Objects (HCD)	Foil Objects	Target Objects (LCD)	Foil Objects	Target Objects (HCD)	Foil Objects	Target Objects (LCD)	Foil Objects
Fire engine	Patrol car	Frying pan	Kitchen knife	Crow	Pigeon	Chicken	Owl
Ambulance	Truck	Desk	Sofa	Pimento	Carrot	Ant	Ladybird
Piano	Violin	Dish	Chopsticks	Tomato	Eggplant	Monkey	Cow
Trumpet	Recorder	Guitar	Saxophone	Banana	Apple	Horse	Pig
Eraser	Pen	Socks	Skirt	Strawberry	Peach	Sparrow	Parakeet
Shirt	Trousers	Scissors	Notebook	Rabbit	Cat	Elephant	Giraffe
Spoon	Glass	Sports car	Station wagon	Locust	Dragonfly	Dog	Bear