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The influence of surface color information and color knowledge information in object recognition

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In order to clarify whether the influence of color knowledge information in object recognition depends on the presence of the appropriate surface color, we designed a name–object verification task. The relationship between color and shape information provided by the name and by the object photo was manipulated in order to assess color interference independently of shape interference. We tested three different versions for each object: typically colored, black and white, and nontypically colored. The response times on the nonmatching trials were used to measure the interference between the name and the photo. We predicted that the more similar the name and the photo are, the longer it would take to respond. Overall, the color similarity effect disappeared in the black-and-white and nontypical color conditions, suggesting that the influence of color knowledge on object recognition depends on the presence of the appropriate surface color information.

The role of surface color in object recognition (i.e., the color present in the image of an object) is an unresolved issue in cognitive science. For example, theories differ on the role shape plays in object recognition (Biederman, 1987; Marr & Nishihara, 1978) and whether other object features, such as surface details, texture, and color, contribute to object recognition (Tanaka, Weiskopf, & Williams, 2001; Tarr, Williams, Hayward, & Gauthier, 1998). Different studies have suggested different roles for color in object recognition. For example, color serves as a perceptual input to early stages of visual processing (Davidoff, Walsh, & Wagemans, 1997; Wurm, Legge, Isenberg, & Luebker, 1993) and is part of the structural representation system of the objects (Price & Humphreys, 1989) or of the semantic system (Davidoff et al., 1997; Tanaka et al., 2001). Moreover, color serves as an important cue in object retrieval processes (Lloyd-Jones, 2005; Lloyd-Jones & Nakabayashi, 2009; Vernon & Lloyd-Jones, 2003).

Although it is not yet clear at which level surface color facilitates object recognition, there is a consensus that colored objects and visual scenes are recognized faster than corresponding noncolored versions (Oliva & Schyns, 2000; Rossion & Pourtois, 2004). In order for surface color to be a useful cue for recognition, the participants must decide whether a color is appropriate for a particular object, and it seems

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plausible that semantic object information (including stored color knowledge) has to be accessed for this to occur. This suggests that prior color knowledge plays a role in object recognition in addition to surface color input, because the color input must in some sense be checked against the activated prototypical color of the object.

In order to study how surface color input and prior color knowledge interact, Joseph and Proffitt (Joseph, 1997; Joseph & Proffitt, 1996) manipulated color knowledge and surface color input independently in a series of verification tasks. The authors found that prior color knowledge was more influential than perceptual input color; for example, a *purple apple* was more likely to be mistaken for a *cherry* (typically red) than for a *blueberry* (typically purple). It was argued that the interference effect is explained by the fact that apples and cherries are prototypically red and not because the apple was colored in purple, the typical color of blueberries. The same pattern of results was obtained when uncolored pictures were used, suggesting that the semantic processing of color is independent of the presence of a perceptual input color.

However, the authors did not fully control whether the interference was caused by prior shape knowledge. In their verification tasks the participants were asked to verify a target object against three different types of distractors: a distractor similar in shape but not similar in color, a distractor similar in shape and color, and a distractor that was dissimilar in both shape and color. To rule out a possible shape interference effect, it is important to include a fourth distractor type that is similar in color and dissimilar in shape. Because shape information is needed for object identity, strong similarity in shape will influence the verification decision. Thus it is important to investigate the previous findings (Joseph, 1997; Joseph & Proffitt, 1996) by controlling color knowledge interference fully independent of shape knowledge interference.

In this study we investigated whether prior color knowledge information takes place in object recognition independently of the presence of the appropriate surface color, controlling the shape information. We designed a verification task in which an object name was presented before an object picture. Two types of trials were included: matching (the name matches the picture) and nonmatching (the name does not match the picture). On nonmatching trials, the name might activate shape and color knowledge that interferes with shape and color information provided by the picture. To test whether the role of color knowledge information in object recognition is dependent on the presence of the appropriate surface color, three different versions of each object were tested: typically colored, black and white, and nontypically colored. If color knowledge information contributes to the recognition process, independently of the presence of the appropriate surface color, it should be more difficult to say "no" whenever the color knowledge activated by the name and by object picture is the same, not only when pictures are presented in their typical color version but also when black-and-white and atypical color versions are presented. In order to assess color interference independently of shape interference, the relationship between color and shape information provided by the name and by the picture was manipulated to assess four possible mismatches: dissimilar shape and dissimilar color, dissimilar shape and similar color, similar shape and dissimilar color, and similar shape and similar color. The interference in the response was measured by the longer response times (Joseph, 1997; Joseph & Proffitt, 1996).

A second aim of this study was to explore the role of color diagnosticity in object recognition. Color diagnosticity is the degree to which a particular object is associated with a specific color. For example, a *strawberry*—a diagnostic color object—is clearly associated with the *red* color, whereas a *comb*—a nondiagnostic color object—is not strongly associated with any specific color. According to the color diagnosticity hypothesis (Tanaka & Presnell, 1999), surface color information improves the recognition of diagnostic but not nondiagnostic color objects (see also Nagai & Yokosawa, 2003). However, Rossion and Pourtois (2004) documented that colored objects, independent of the diagnosticity status, were named faster than their noncolored versions (see also Biederman & Ju, 1988; Uttl, Graf, & Santacruz, 2006; Wurm et al., 1993). Although color diagnosticity is an important aspect to control when the influence of color information is being studied in object recognition, its role is not well understood. In an attempt to clarify this question, we used in our verification task both diagnostic and nondiagnostic color objects. If surface color information is engaged during recognition of both diagnostic and nondiagnostic color objects, then the name–picture matching should be faster with typical colored than with black-and-white and atypical color pictures, for both diagnostic and nondiagnostic objects.

EXPERIMENT

METHOD

Participants

Twenty-eight Portuguese graduate students with normal or corrected-to-normal vision volunteered to participate in the experiment (mean age [$\pm SD$] = 22 ± 4 years; mean school years [$\pm SD$] = 14.5 ± 1 years).

Stimuli

The initial pool of pictures consisted of 62 photos of common objects selected from the Reis, Faísca, Ingvar, and Petersson (2006) set. An independent group of 30 participants named and rated the initial set according to prototypicality, familiarity, visual ambiguity, visual complexity, and color diagnosticity. Each photo was presented for 1 min, and participants were asked to write down the name of the object. If they did not know the name, they were asked to mark one of the following categories: "do not know the name," "do not know the object," or "tip-of-the-tongue." Participants were also asked to evaluate the prototypicality of each photo "according to the degree that the presented picture represents a typical exemplar of the concept" and rated the degree of agreement between the presented photo and their mental image of the concept using a 5-point scale, where 1 indicated low agreement and 5 indicated high agreement. The familiarity of each photo was judged "according to how usual or unusual the object is in your realm of experience," and the participants were asked to rate the concept itself, rather than the photo, using a 5-point rating scale (1 = *very unfamiliar,* 5 = *very familiar*). The visual ambiguity of each photo was evaluated "according to how large is the group of different objects that are visually similar with the presented object" (5-point rating scale: 1 = *completely nonambiguous object,* 5 = *completely ambiguous object*). Visual complexity was defined as "the amount of detail or intricacy of line in the photo," and the participants were told to rate the photo itself rather than the real-life object (5-point scale: 1 = *very low visual complexity,* 5 = *very complex picture*). Color diagnosticity was defined as "the degree to which the object is associated with a specific color" and was also rated on a 5-point scale (1 = *low diagnostic color,* 5 = *high diagnostic color*). These instructions are similar to the ones typically used in rating studies (Rossion & Pourtois, 2004; Snodgrass & Vanderwart, 1980; Ventura, 2003).

Following the analysis of the rating scores, we selected only the photos that showed at least 80% name agreement between participants. From these, we selected 16 photos to be used in the experiment: 8 representative of diagnostic color objects (apple, tomato, carrot, orange, pineapple, pear, onion, and lemon) and 8 representative of nondiagnostic color objects (book, glasses, bowl, pencil, water, can, ruler, and comb). The only significant mean difference between the two groups of objects was color diagnosticity. The mean comparisons between diagnostic and nondiagnostic items on the other rating variables were nonsignificant ($p > .5$; Table 1).

Each colored photograph was used to create a black-and-white version (using Adobe Photoshop 7.0 "grayscale mode" command, which preserves luminance while discarding color) and a nontypi-

TABLE 1. Mean (*SD*) ratings of color diagnosticity, prototypicality, familiarity, visual ambiguity, and visual complexity for diagnostic and nondiagnostic color objects

	Diagnostic color objects	Nondiagnostic color objects	Mann–Whitney U test
Color diagnosticity	4.4 (0.4)	2.3 (0.6)	$Z = 3.4$, $p < .001$
Prototypicality	4.6 (0.2)	4.5 (0.2)	$Z = 0.6$, $p = .5$
Familiarity	4.7 (0.1)	4.6 (0.3)	$Z = 0.3$, $p = .8$
Visual ambiguity	1.9 (0.2)	1.8 (0.3)	$Z = 0.4$, $p = .7$
Visual complexity	2.3 (0.5)	2.4 (0.6)	$Z = -0.4$, $p = .7$

cally colored version[1] (using Adobe Photoshop 7.0 "variations" command, until a complete transformation of object color was obtained, which preserves luminance). Stimuli luminance was measured using Adobe Photoshop 7.0. We did not find any statistical difference between the diagnostic and nondiagnostic items for the three color versions concerning the luminance values (overall, Mann–Whitney U test: $|Z| = 0.7, p > .30$).

Procedures

A computerized verification task was designed in which an object picture was preceded by an object name. Participants had to decide whether the name and the picture matched. The verification task consisted of 768 trials; half of the trials were matching (384 trials in which the name and the picture matched) and half were nonmatching (384 trials in which the name and the picture did not match). On matching trials, the same object was presented eight times in each version (16 objects × 3 versions × 8 times each). On the nonmatching trials, 192 trials involved only diagnostic color objects in order to test the interference of shape and color (8 diagnostic color objects × 3 versions × 8 times each); in the remaining 192 trials, diagnostic and nondiagnostic color objects were used as fillers (16 objects × 3 versions × 4 times each). The 192 nonmatching trials with diagnostic objects were designed to assess the four possible mismatches between color and shape knowledge activated by the name and the picture (shape/color: dissimilar/dissimilar, similar/dissimilar, dissimilar/similar, and similar/similar; see Figure 1).

In order to confirm that the four possible mismatches actually activated the same/different color and shape information, 30 independent participants rated the four pairs according to shape and color similarity. The names of the four pairs of stimuli were presented together with four filler pairs, and participants were asked to rate the shape and color similarity between the two concepts. Shape similarity was judged "according to how similar are the two objects in terms of their global shape" (5-point scale: 1 = *the two objects have two completely different shapes,* 5 = *the two objects share the same global shape*). Color similarity was evaluated "according to how similar are the colors of the two objects" (5-point scale: 1 = *the color of the two objects is completely different,* 5 = *the two objects share the same color*). We confirmed that the pairs "tomato–apple" and "onion–lemon" are more similar in term of their global shape, 4.1 ± 0.6, compared with the pairs

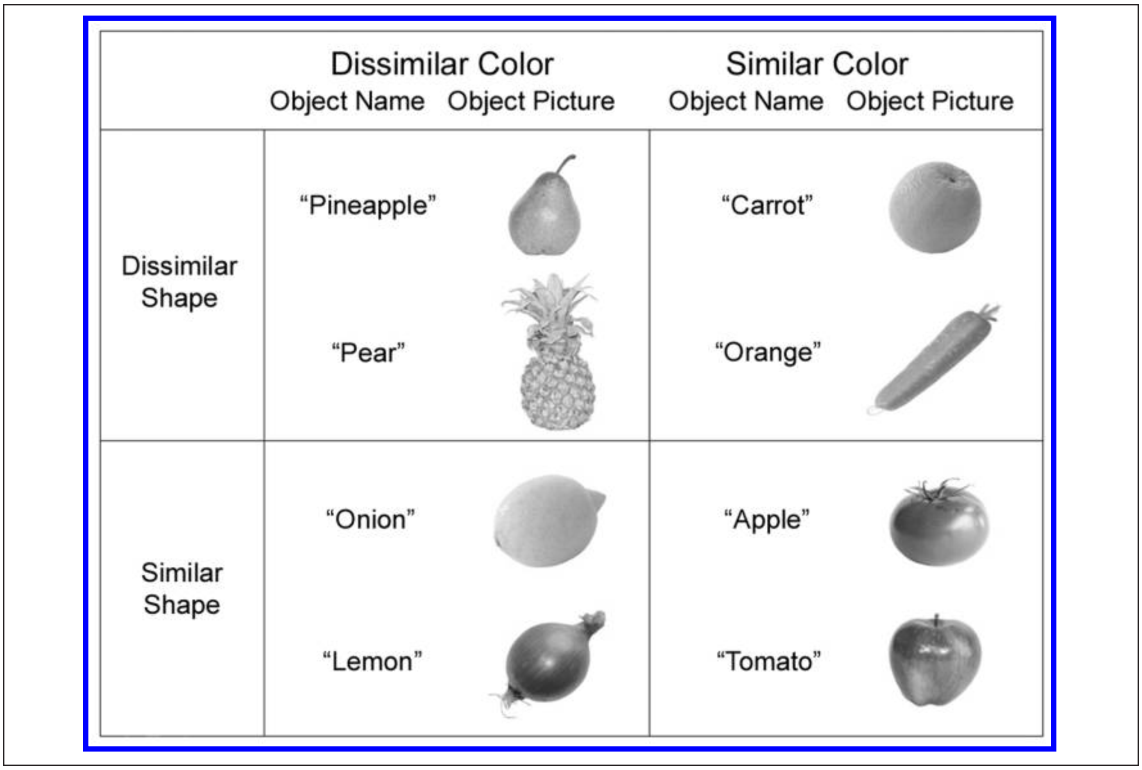

FIGURE 1. Stimuli used in the 4 possible mismatches between the name and the photo for nonmatching trials

"carrot–orange" and "pineapple–pear," 1.2 ± 0.5; $F(1, 29) = 818.6$, $p < .001$. We also confirmed that the pairs "tomato–apple" and "carrot–orange," 4.2 ± 1.0, are more similar in terms of their color than the pairs "onion–lemon" and "pineapple–pear," 1.6 ± 0.6; $F(1, 29) = 447.8$, $p < .001$.

The Presentation 0.7 software (http://www.neurobs.com/presentation) was used to display the stimuli on a computer screen (size, 17″; spatial resolution, 1,024 × 768; color resolution, 24 bits) and to register response times. Each trial started with a fixation cross presented at the center of the screen for 1,000 ms. After the fixation cross, the object name (font Arial, font size 70) was presented for 1,000 ms, followed by a 500-ms blank screen and then the presentation of the object picture (760 × 550 pixels) for 120 ms. The trial ended with the participant's response. After 1,000 ms a new trial started. Participants were instructed to decide as accurately and as quickly as possibly whether the name and the picture matched by pressing one of the two response keys of the keyboard (half of the participants used the right/left hand for "yes"/"no" and the other half for "no"/"yes"). The 768 trials were split into four blocks of 192 trials each. Both blocks and trials within blocks were randomized, and participants were allowed to pause between blocks. Before the experiment, each participant completed a training session with 20 trials.

RESULTS

The results of the nonmatching and matching trials were analyzed by subject ($F1$) and by stimulus ($F2$). A minimum F (min$F$) was calculated from the $F1$ and $F2$ analyses. We report $F1$, $F2$, and min$F$ values; however, our conclusions are based solely on the conservative min$F$ analysis. This approach was taken to ensure the generalizability of results over both subject and stimulus domains (Clark, 1973; Raaijmakers, 2003; see also Raaijmakers, Schrijnemakers, & Gremmen, 1999). None of the main effects or interactions that fail to reach significance in the min$F$ procedure are reported.

Nonmatching trials

The nonmatching trials included two different types of trials: 192 trials with diagnostic objects that were created to test the interference of shape and color on object verification and 192 trials that served as fillers. Because the experimental question was related exclusively to the diagnostic objects trials, only these verification times were analyzed further. Overall, the participants were able to correctly verify almost all stimuli, and we focused our analysis on the verification times from the correct trials with latencies within 2.5 standard deviations of the mean for each participant and condition. We excluded verification times of incorrect responses as well as long and short verification times (in total, 7.5%; 0.9% long; 0.05% short; 6.5% incorrect) from the analysis. The mean of correct response times and the percentage of correct responses for each condition are given in Table 2.

Verification times were analyzed with a repeated-measures ANOVA including presentation version (typical, black and white, nontypical color) as a within-subject or stimulus factor, and shape similarity (similar shape, dissimilar shape) and color similar-

TABLE 2. Mean response time (RT, in ms) and percentage of correct responses for each nonmatching condition

		Presentation mode					
		Typical color		Black and white		Nontypical color	
		RT (*SD*)	% Correct (*SD*)	RT (*SD*)	% Correct (*SD*)	RT (*SD*)	% Correct (*SD*)
Color	Shape						
SC	SS	641 (119)	89 (10)	602 (114)	89 (13)	625 (125)	91 (8)
SC	DS	621 (133)	93 (8)	578 (132)	97 (4)	562 (124)	97 (4)
DC	SS	595 (144)	95 (6)	606 (119)	96 (7)	613 (107)	92 (10)
DC	DS	576 (111)	95 (7)	559 (114)	97 (5)	573 (129)	90 (8)

Note. *DC = dissimilar color between word and image; DS = dissimilar shape between word and image; SC = similar color information between word and image; SS = similar shape between word and image.*

ity (similar color, dissimilar color) were considered within-subject factors in the subject analysis and between-stimuli factors in the item analysis. The results showed a significant presentation version effect, $F1(2, 54) = 9.7, p < .001$; $F2(2, 8) = 6.6, p = .02$; $\min F(2, 21) = 3.39, p = .035$. A post hoc comparison (Tukey's HSD) for the subject analysis showed that the interference was greater on verification times with typical presentations compared with black-and-white presentations ($p < .001$) and with nontypical presentations ($p = .02$); a main effect of shape similarity was observed, $F1(1, 27) = 44.3, p < .001$; $F2(1, 4) = 85.7, p < .001$; $\min F(1, 22) = 29.23, p < .001$. When shape information between the object name and the object depicted in the photo was similar, there was greater interference compared with the dissimilar case; a main effect of color similarity was also observed, $F1(1, 27) = 28.6, p < .001$; $F2(1, 4) = 21.36, p = .001$; $\min F(1, 11) = 12.22, p = .005$. When the color information between the object name and the object picture was similar, there was greater interference than in the dissimilar case. The two-way interaction between presentation version and color similarity was significant, $F1(2, 54) = 10.1, p < .001$; $F2(2, 8) = 10.6, p = .006$; $\min F(2, 29) = 5.17, p = .012$ (Figure 2). A Tukey HSD post hoc comparison for the subject analysis showed that when the color activated by the name and by the object picture was dissimilar, the verification time was equivalent for the three presentation versions, $p > .90$. In contrast, when the name and the picture activated the same color, the interference was larger with typical than with black-and-white and nontypical color presentations, $p < .001$.

Matching trials

As in the case of the nonmatching trials, the participants made very few errors on the matching trials (less than 5%). The participants were able to correctly verify almost all stimuli, and we focused our analysis on the verification times from the correct trials with latencies within 2.5 standard deviations of the mean for each participant and condition. We excluded response times from incorrect trials as well as any long or short verification times (in total, 5.8%; 0.8% long; 0.2% short; 4.8% incorrect) from the analysis. The mean of correct response times and the percentage of correct responses for each condition are given in Table 3.

The verification times were analyzed with a repeated-measures ANOVA considering the presentation type (typical, black-and-white, nontypical color) as a within-subject or stimulus factor and diagnosticity

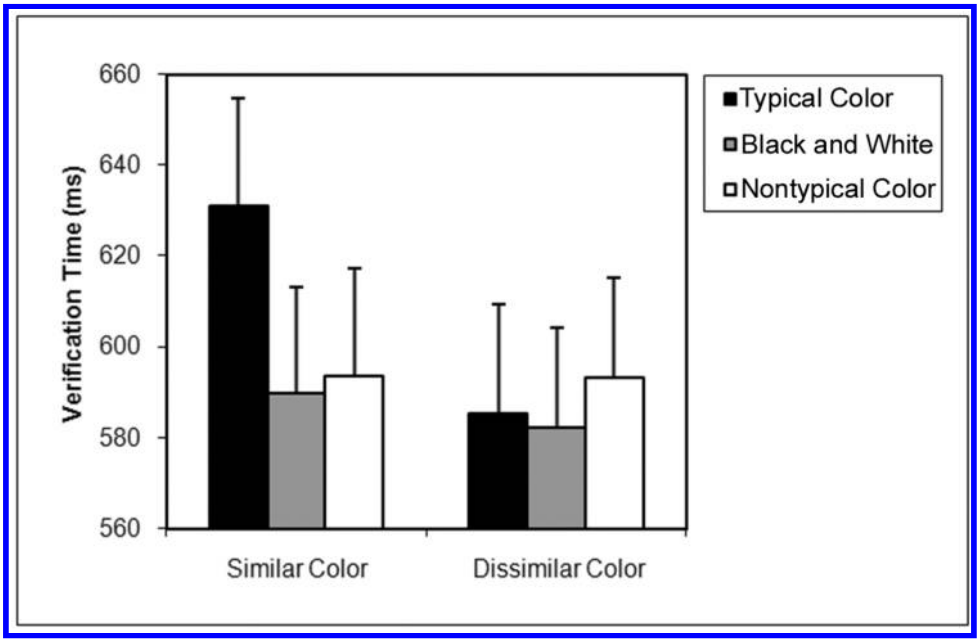

FIGURE 2. Two-way interaction between presentation version and color similarity on nonmatching verification times. Bars represent standard error

TABLE 3. Mean response time (RT, in ms) and percentage of correct responses for each nonmatching condition

	Presentation mode					
	Typical color		Black and white		Nontypical color	
	RT (*SD*)	% Correct (*SD*)	RT (*SD*)	% Correct (*SD*)	RT (*SD*)	% Correct (*SD*)
Diagnostic color objects	522 (91)	94 (5)	542 (88)	93 (7)	556 (105)	91 (7)
Nondiagnostic color objects	455 (88)	98 (3)	471 (92)	97 (3)	468 (93)	97 (2)

(diagnostic, nondiagnostic color objects) as a within-subject factor to the subject analysis and between-stimuli factor to the item analysis, with the correct verification times for matching trials as the dependent variable. The results showed a significant presentation version effect, $F1(2, 54) = 21.2$, $p < .001$; $F2(2, 28) = 9.6$, $p < .001$; $\min F(2, 53) = 6.60$, $p = .003$. A post hoc comparison (Tukey HSD) for subject analysis showed that participants were faster verifying objects presented in typical compared with black and white and nontypical color, $p < .001$; there was also a significant effect of diagnosticity, $F1(1, 27) = 165.6$, $p < .001$; $F2(1, 14) = 74.5$, $p < .001$; $\min F(1, 27) = 51.36$, $p < .001$. Participants were faster verifying nondiagnostic compared with diagnostic color objects. Note that the interaction between presentation version and diagnosticity was not observed (Figure 3).

DISCUSSION

The main aim of this study was to investigate the role of prior color knowledge in object recognition and to test whether and how it interacts with surface color input in object recognition. Participants were presented with an object name, and they had to decide whether the name matched a subsequently presented

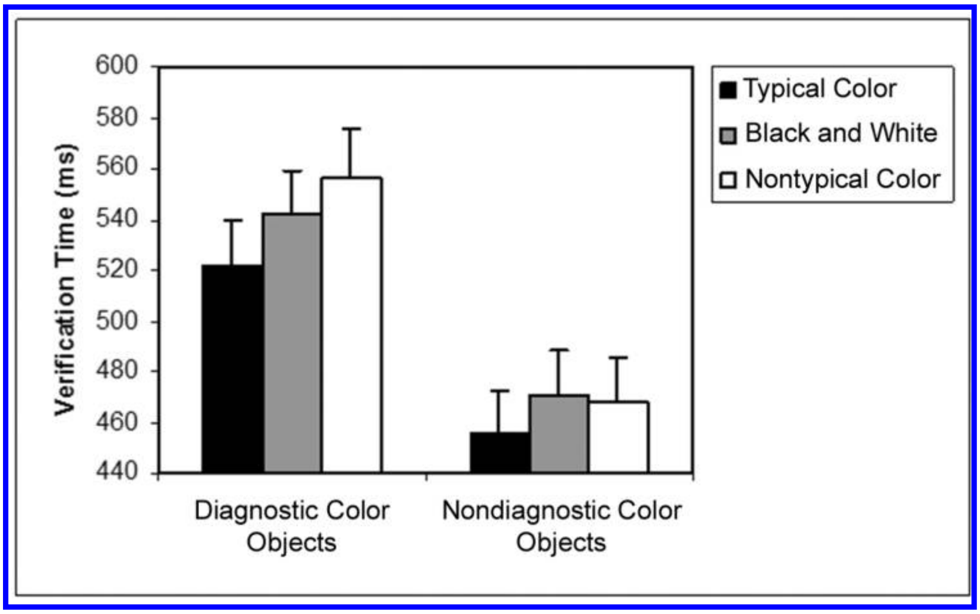

FIGURE 3. Two-way interaction between presentation version and color diagnosticity on matching verification times. Bars represent standard error

object picture. The verification times on the nonmatching trials were used to measure the interference between the name and the picture. The interference in the response was measured by the longer response times (Joseph, 1997; Joseph & Proffitt, 1996). We predicted that the greater similarity, in terms of shape and color, between the object named and the object pictured, the longer the participants would take to decide whether the name and the picture designated the same or a different object. This was indeed the case. The nonmatching verification times were longer when color knowledge activated by the object name was the same as the visual information received from the object picture compared with the conditions in which these two sources provided different color information. This suggests, as expected, that prior color knowledge is recruited during object recognition. In addition, we found a strong interference effect of shape information on the nonmatching trials, suggesting that prior shape knowledge is activated in parallel with color knowledge.

The important finding in our study was that the color similarity effect disappeared in the black-and-white and nontypical colored conditions, while the interference of shape remained. It thus appears that the activation of prior color knowledge depends on the presence of the appropriate surface color information: The absence of surface color or wrong surface color neutralizes the observed interference effect. Color knowledge information per se does not seem to play an important role in object recognition. The information activated by the word *orange* interfered with the information activated by the picture *carrot* only when the orange was presented in its typical color version and not when the orange was presented in black and white or in its atypical color version. This finding suggests that it is the appropriate surface color input that promotes the activation of the color knowledge information in the cognitive system. Looking into our data, we could also speculate that color knowledge information is equally important in all conditions as the basis for a rapid heuristic decision, and, consequently, whenever there is not a match between the color information activated by the word and by the image, another criterion must be used to reject the nonmatching combination, and this leads to longer response times. If this were the case, the black-and-white object presentations would also have activated the same color knowledge information as the object word, and then another criterion would be used in order to reject the combination, and consequently the response times should have been also longer. Nevertheless, this was not the case. The explanation that better fits our data is that the appropriated surface color input promotes the color knowledge activation.

Tanaka and collaborators (Tanaka et al., 2001) proposed the "Shape + Surface" object recognition model, which suggests that object recognition is jointly determined by the bottom-up influence of the surface color and the top-down influence of the color knowledge. Our results show that the top-down influence of color knowledge is in some way dependent on the bottom-up influence of surface color, suggesting that the color present on the image is responsible for the activation of the stored color information.

Additionally, the results for matching trials showed a robust surface color effect; participants were faster verifying objects presented in their typical color compared with black and white or nontypical color. We also found a strong color diagnosticity effect; the verification times were longer for diagnostic color objects compared with nondiagnostic color objects. This finding might be related to the fact that the diagnostic objects in our study were all from natural categories, whereas the nondiagnostic color objects were all from artifact categories. Consistent with this suggestion are the results from studies that investigated category-specific effects in healthy participants. The general pattern of results that emerges from these studies is a recognition advantage for objects from artifact compared with natural categories when the viewing conditions are optimal. Recently Gerlach and collaborators (Gerlach, 2009; Gerlach, Law, & Paulson, 2006; for a different perspective, see Laws & Hunter, 2006) proposed that category-specific effects are driven by the specific processing demands imposed by a given task. Because the shapes of natural objects are more easily configured than the shapes of artifacts, any manipulation that limits how much information may be extracted from the visual impression will make shape configuration harder and would make artifact recognition harder than natural object recognition (see Laws & Neve, 1999; Lloyd-Jones & Luckhurst, 2002). However, if the demand on structural differentiation is high and task conditions are optimal, the shape configuration disadvantage for artifacts may be compensated by more competition for natural objects at the level where visual long-term memory representations compete for selection (see Coppens & Frisinger, 2005; Humphreys, Riddoch, & Quinlan, 1988; Lloyd-Jones & Humphreys, 1997). This is in agreement with our results, where the task viewing conditions were optimal.

Moreover, we found that surface color information helps the recognition of both diagnostic and nondiagnostic color objects. Our results are in concordance with Rossion and Pourtois (2004). The authors did not find a correlation between color diagnosticity and naming latencies, and they argued that color information is an important cue for both diagnostic and nondiagnostic object recognition (see also Biederman & Ju, 1988; Uttl et al., 2006; Wurm et al., 1993).

In conclusion, the present study demonstrated that prior color knowledge is engaged during object recognition. However, its role depends on the presence of the surface color input. We suggest that the top-down influence of color knowledge, described in the "Shape + Surface" (Tanaka et al., 2001) object recognition model, is driven by the bottom-up influence of appropriate surface color information. Additionally, our results provide evidence that surface color is an important cue to recognize both diagnostic and nondiagnostic color objects.

NOTES

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1. For the nondiagnostic color objects we did not construct a nontypical color version but just another color version of the same object, because these objects do not have a nontypical color associated with them. When we refer to a nontypical color version of the nondiagnostic color objects we just mean a second color version of the same object.

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