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RESEARCH REPORT

The role of color diagnosticity in object recognition and representation

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Abstract The role of color diagnosticity in object recognition and representation was assessed in three Experiments. In Experiment 1a, participants named pictured objects that were strongly associated with a particular color (e.g., pumpkin and orange). Stimuli were presented in a congruent color, incongruent color, or grayscale. Results indicated that congruent color facilitated naming time, incongruent color impeded naming time, and naming times for grayscale items were situated between the congruent and incongruent conditions. Experiment 1b replicated Experiment 1a using a verification task. Experiment 2 employed a picture rebus paradigm in which participants read sentences one word at a time that included pictures of color diagnostic objects (i.e., pictures were substituted for critical nouns). Results indicated that the "reading" times of these pictures mirrored the pattern found in Experiment 1. In Experiment 3, an attempt was made to override color diagnosticity using linguistic context (e.g., a pumpkin was described as painted green). Linguistic context did not override color diagnosticity. Collectively, the results demonstrate that color information is regularly utilized in object recognition and representation for highly color diagnostic items.

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Introduction

Observers could use a host of different types of information to recognize everyday objects in their environment. However, the speed of object recognition suggests that there is a minimal set of critical features that are initially monitored. Of particular interest to researchers is the contribution of edge (i.e., shape) and surface (i.e., color, texture, viewpoint) information in object recognition.

Researchers typically emphasize an *edge-based* or a *surface + edge-based* characterization of object recognition. Edge-based theories posit that a finite set of structural components (e.g., 36 geons) is used in object recognition (Biederman 1987; Biederman and Gerhardstein 1993; Biederman and Ju 1988; Grossberg and Mingolla 1985). Geons are derived from contrasts of two-dimensional edges based upon their curvature, symmetry, parallelism, and cotermination. According to the Recognition-by-Components model, object recognition is primarily driven by object shape (Biederman and Bar 1999; Biederman and Gerhardstein 1995), whereas color, brightness, surface texture, and orientation represent secondary routes to object recognition (Biederman and Ju 1988; Cave et al. 1996). For example, color information may be informative for object recognition insofar as it helps observers extract edge information by increasing the contrast between objects. Color information could also be used to distinguish between similarly shaped objects (e.g., orange, lemon, or lime) or objects with degraded or extremely variable shape information (e.g., chewing gum, laundry). In contrast, surface + edge-based characterizations of object recognition assert that color, texture, and various viewpoints can be directly utilized, in addition to shape information, to recognize objects (Hayward and Williams 2000; Naor-Raz et al. 2003; Price and Humphreys 1989; Tanaka and Presnell 1999; Tarr and Bülthoff 1995; Wurm et al. 1993).

One research approach assessing the merits of structural (i.e., edge based) and image views (i.e., surface + edge-based) has been to examine the contribution of specific feature information (e.g., color) at various levels of object identification/representation. With regard to color information, contrasting evidence for its use in object recognition has been documented. A brief review of this body of evidence follows.

Edge-based evidence

In support for the edge-based view, Biederman and Ju (1988) demonstrated that the reaction times to name or verify line drawings of objects approximated reaction times to name or verify fully-detailed color pictures of the same objects. They argue that these results underscore that shape is the critical feature driving object recognition. If surface information (i.e., color) contributed to object recognition, the photographs should have elicited faster recognition or verification times than their line drawing counterparts.

Ostergaard and Davidoff (1985) have also explored the effects of color on object naming and recognition and observed a conflicting pattern. They reported that color pictures were named faster than black-and-white pictures. Interestingly, this effect did not carry over to an object recognition task. That is, inappropriately colored objects did not inhibit object recognition (Experiments 2 and 3). Ostergaard and Davidoff concluded that the main role of color is to attract attention to other, potentially more useful, types of feature information (i.e., shape information). In subsequent work, Davidoff and Ostergaard (1988) observed that appropriately or inappropriately colored objects did not influence response times in a semantic classification task. They argue that color information is separate from the semantic representation of objects (i.e., the representation of color information about objects is stored as ancillary verbal information).

Surface + edge based evidence

Evidence has also been gathered supporting the claim that color can be used in object recognition and categorization. For example, Tanaka and Presnell (1999) presented participants with an object classification task, in which two words were simultaneously presented left and right of a center point followed by a (high color diagnostic, HCD or low color diagnostic, LCD) picture presented at the center point. Participants verified if the picture matched the previously presented words. Results indicated that color facilitated recognition of HCD objects, but had little effect on the recognition of LCD objects. In a subsequent naming study, Tanaka and Presnell (1999) found that color versions of HCD objects were named faster and more accurately than achromatic HCD objects. However, when participants named LCD objects there were no differences between color and achromatic versions. This pattern of results led Tanaka and Presnell to conclude that color does play a role in the recognition of objects, but only those with strong color associations.

Naor-Raz et al. (2003) explored the role of color information using a variation of the Stroop paradigm in which participants named the displayed colors of objects or words. Participants named matched color objects more quickly than mismatched objects (i.e., a yellow banana was named more quickly than a purple banana). Naor-Raz et al. concluded that color is an intrinsic property of object representation. Similarly, Rossion and Pourtois (2004) provide evidence for a naming accuracy and response time advantage of color objects over black-and-white line drawings or grayscale texture/surface detail counterparts. There was a stronger effect for color diagnostic items but an effect was also obtained using man-made objects and objects that did not have a single diagnostic color.

The present studies

Many aspects of the role of color information in object recognition remain open questions (Rossion and Pourtois 2004; Tanaka et al. 2001). The studies reviewed above provide mixed findings, warranting further investigation. One important task is to examine the level at which color information might influence naming, recognition, and representational processes. Experiments 1a and 1b were designed to extend previous color-diagnosticity research by including color stimuli from multiple sources and providing additional experimental control. Specifically, stimuli in the present experiments were adapted from Naor-Raz et al. (2003) and Tanaka and Presnell (1999) high-color diagnostic items. Further experimental control was obtained by including a no-color condition (in addition to our color manipulation). Having three conditions (congruent color, incongruent color, and grayscale) provides a means to directly assess whether the main role of color is to attract attention to shape information and helps to more precisely gauge the contribution of color to naming and recognition processes.

In Experiment 1a, naming latencies were collected for HCD objects that were rendered in a diagnostically congruent color, incongruent color, or in grayscale. If color is available in object recognition, then a specific naming latency pattern should emerge. Namely, the congruent version should elicit the quickest responses (color facilitation), followed by the grayscale version (no color information), and finally, the incongruent version of the object (color interference). In Experiment 1b, the goal was to explore the possibility that color information might be utilized during object representation/visualization, and thus, beyond the level of object recognition. In our experiment, color diagnostic object words were presented followed by a color congruent, color incongruent, or grayscale version of the image in a verification task. The task promotes the visualization of the object and, potentially, its diagnostic color. If color information is included in the representation of color diagnostic objects, then the pattern of verification reaction times should mirror the results obtained in Experiment 1a. Experiment 2 examined the possibility that color information is utilized in a task in which the recognition of pictured objects is ostensibly incidental. Experiment 3 explored the extent to which linguistic context influences the recognition of color diagnostic objects.

Experiment 1a

It is important to revisit the mixed results regarding the status of color influence. One possible explanation for prior conflicting color findings is the manner in which color diagnosticity is determined. For example, Tanaka and Presnell (1999) reported that many of the objects classified as HCD in the original Biederman and Ju (1988) study (fish, nail, fork, flowerpot, and camera) were actually classified as LCD items in their experiments. Consequently, no items identified as LCD items were included as stimuli. The bulk of our images were adapted from Naor-Raz et al. (2003) and Tanaka and Presnell (1999) HCD lists. Our color diagnostic items were selected using pragmatic criteria: (1) was it listed as a HCD in previous literature (and not flagged as a bad item in any other study), (2) could we balance these items across the spectrum of colors items used, and (3) was there a quality image we could draw upon. It is interesting to note that many of these items are foods or designed specifically with color in mind (e.g., strawberry or stop sign).

Proponents of edge-based theories often explain color effects in terms of shape information. That is, color effects only occur because color information indirectly informs participants about edge and shape information (i.e., color provides shape information through contrast and luminance). In an attempt to minimize the indirect shape information provided by color, our photographs were first transformed to gray-scale, and then painted with translucent congruent or incongruent colors to create the various levels of color diagnosticity.

Method

Participants

Eighty-four undergraduate students enrolled at The Florida State University in introductory psychology courses participated for course credit. All subjects were native English speakers.

Materials

Ninety-six pictured objects were created: 24 experimental and 72 filler items. Experimental pictures included a color-diagnostic object (e.g., pumpkin) in one of three potentially differently colored versions (see Fig. 1). The colored versions of each object were: congruous (e.g., an orange pumpkin), neutral (e.g., a grayscale pumpkin), or incongruous (e.g., a teal pumpkin). The 72 filler pictures were judged not to be color diagnostic and were randomly colored such that there were an equal number of similarly colored objects.

The 96 pictured objects were scaled to occupy a square of approximately three inches (72 pixels per square inch). We used the program Adobe Photoshop for all image editing. Images were modified uniformly by removing all color information using a mode transformation to grayscale. Color information was then reapplied to the objects by overlaying a translucent layer of color according to the standard RGB value for each color (blue, green, red, cyan, orange, brown, yellow, purple, pink, violet, or teal). By applying the same colors to the objects the variability of similarly colored objects (e.g., the difference between the orange of a pumpkin and of a traffic cone) was removed. Three levels of color (neutral, congruent, and incongruent) were varied across all pictures. Twenty-four of these pictures were experimental items (i.e., color diagnostic objects). All pictures appeared against a white background. A listing of all color diagnostic items is presented in the Appendix.

Fig. 1 Example stimuli

Procedure

Three lists were created counterbalancing items and conditions. Each list included experimental items in one of three (object color: congruent/neutral/incongruent) possible versions. Each participant saw only one list. Object color was a within-participants factor. Congruent, neutral, and incongruent conditions were balanced across all lists. Each participant saw 24 experimental word-picture pairs (8 congruent, 8 neutral, and 8 incongruent), requiring affirmative responses, 28 filler pairs requiring affirmative responses, and 44 filler pairs requiring negative responses. Thus, there were 52 word-picture pairs requiring affirmative and 44 requiring negative responses.

The experiment was run on PCs with 19″ flat-screen displays using the E-Prime stimulus presentation software (Schneider et al. 2002). Screen resolution was set at 1,024 × 768 and participants sat roughly 24 inches from the screen. During each trial, a fixation cross appeared for 250 ms, after which a pictured object was presented in the center of the screen. Participants were instructed to name the pictured object as quickly and accurately as possible as both naming time and accuracy of response were being measured. Responses were recorded using a head-mounted microphone. An experimenter remained in the room with the participant to log incorrect responses. The experiment took approximately 15 min to complete. Upon completion the experiment, the participant was tested for color blindness. No data from colorblind individuals was included in analyses.

Design and analyses

Responses longer than 2,000 ms or shorter than 100 ms were omitted, as well as responses falling outside 2 standard deviations from the participant's mean in the respective condition. Latency analysis was performed on correct responses only. Three of the experimental items yielded high error rates (i.e., subjects had trouble identifying the object, or did not know what the object was). These items (artichoke, lime, and cantaloupe) were omitted from the following analyses. The outlier procedures resulted in eliminating 6.1% of the data (well within an acceptable range given the nature of reaction time data, Ratcliff 1993). Naming latencies of experimental trials were submitted to a 3(Congruent vs. Neutral vs. Incongruent) × 3 (List) mixed factor ANOVA, in which, List was a between-subjects variable.

Results and discussion

Analyses with the subscript 1 refer to by-participants analyses, whereas the subscript 2 refers to by-materials analyses. Both analyses revealed a main effect of color on naming times [F_1 (2, 162) = 16.48, MSe = 183587, $P < 0.001$; F_2 (2, 46) = 4.2, MSe = 4941, $P < 0.05$]. Follow up, a priori, pairwise comparisons confirmed that the congruent condition ($M = 891$ ms) elicited significantly quicker responses than the neutral condition ($M = 923$ ms) and that the neutral condition elicited significantly quicker responses than the incongruent condition ($M = 986$ ms) (all P's < 0.05). These results suggest that congruent color information facilitated naming times for color diagnostic items, whereas incongruent color information interfered with naming times. This provides evidence that color information is routinely utilized when naming pictured color-diagnostic objects.

Experiment 1b

Method

Participants

Eighty-four undergraduate students participated from the same subject pool as described in Experiment 1a.

Materials

The same pictures used in Experiment 1a were paired with the name of the object for Experiment 1b.

Design and procedure

The design (i.e., conditions and filler items used) was identical to that of Experiment 1a, except that a verification procedure was employed. Specifically, participants were presented with an object word and then a picture of an object. They decided if the word matched the picture presented by pressing the 'Y' or 'N' labeled keys on the keyboard.

Design and analyses

Responses falling outside 2 standard deviations from the participant's mean in the respective condition were removed, and analysis was only performed on correct responses. These outlier removal procedures resulted in the elimination of 5.5% of the data. The remaining response times were submitted to a 3 (Congruent vs. Neutral vs. Incongruent) × 3 (List 1 vs. List 2 vs. List 3) mixed factor ANOVA, in which List was a between-subjects variable.

Results and discussion

There was a main effect of color on object verification times [F_1 (2, 162) = 23.06, MSe = 64849, $P < 0.001$;

F_2 (2, 46) = 3.89, MSe = 6408, $P < 0.05$]. Pairwise comparisons confirmed that verification of color diagnostic objects in the congruent condition ($M = 613$ ms) elicited significantly quicker responses than the neutral condition ($M = 640$ ms) and that the neutral condition elicited quicker responses than the incongruent condition ($M = 669$ ms) (all P's < 0.05). Overall, response accuracy was high ($M = 98.4\%$). These results suggest that participants included the color of color-diagnostic objects in their visualization, because presenting images with congruent color facilitated verification decisions, whereas incongruent color information interfered with verification decision times. Thus, it appears that color information is one of the features utilized when constructing a mental image of color-diagnostic objects.

Experiment 2

Experiment 2 was designed to provide a stronger test of the hypothesis that color information facilitates object recognition. We embedded the pictures from Experiments 1a and 1b in sentences, which subjects read one word at a time. They judged whether the sentences made sense or not. The pictures replaced one of the nouns in each sentence. If color information facilitates object recognition, then congruent color objects should be integrated most easily (as indicated by decreased inspection times), followed by the grayscale version of the objects, and finally, the incongruent color version of the objects.

This task provides a very strong test of the hypothesis that congruent color facilitates object recognition for two reasons. First, object recognition ostensibly is not the main focus of the sensibility judgment task, but rather appears to be incidental to it. Second, the occurrence of the picture within the sentence is relatively (compared to naming and verification tasks) unpredictable. Most of the stimuli are words, and only one picture appears per sentence.

Method

Participants

Sixty undergraduate students participated from the same subject pool as described in Experiment 1.

Materials

The pictures from Experiment 1a and 1b were included in sentences using a rebus paradigm (Potter et al. 1986). That is, sentences were created that mentioned experimental objects and the mentioned object words (critical noun) were replaced with the picture of the object. All other words remained the same in sentence and only one picture was presented in each sentence. The picture could appear at any point in the sentence, but never replaced the first or last word of the sentence. Potter et al. provide evidence that when compared to all-word sentences, picture-rebus sentences do not elicit deficits in comprehension (in either speed or accuracy) or immediate recall accuracy.

Ninety-six rebus sentences were created: 24 experimental and 72 filler (i.e., all contained a picture embedded in the sentence). The experimental sentences included a picture of a color-diagnostic object in one of three color conditions (congruent, neutral, or incongruent). Filler sentences included a picture of a non-diagnostic object in one of the three conditions. Forty-eight of the filler sentences were nonsensical (e.g., "The hand petted the pliers and gave it a treat."). The remaining sentences were sensible (i.e., all the experimental sentences and 24 filler sentences).

Design and procedure

The design was similar to Experiment 1, but a sensibility-judgment task was used (i.e., participants judged whether the sentences made sense or not). Participants read each sentence one word (or picture) at a time in a self-paced manner and indicated whether the sentence made sense or not by pressing the 'Y' or 'N' labeled keys on the keyboard.

Design and analyses

Picture-inspection times were screened such that unusually long times (i.e., responses exceeding 2 s) were first removed, followed by 2 standard deviation cutoff from the participant's mean in the respective condition. Analysis was performed only on sentences that elicited correct responses. These outlier removal procedures resulted in the elimination of 6.3% of the data. The remaining inspection times were submitted to a 3 (Congruent vs. Neutral vs. Incongruent) × 3 (List 1 vs. List 2 vs. List 3) mixed factor ANOVA with List as a between-subjects variable.

Results and discussion

There was a main effect of color on picture-inspection times [F_1 (2, 114) = 8.12, MSe = 156488, $P < 0.01$; F_2 (2, 46) = 5.75, MSe = 84499, $P < 0.05$]. The mean inspection time for color congruent objects, neutral objects, and color incongruent objects was 641, 709, and 741 ms, respectively. A priori pairwise comparisons generally supported our prediction; the congruent condition was inspected significantly faster than the incongruent or neutral conditions (both P's < 0.05). The inspection-time difference between the neutral and incongruent conditions did not reach significance (a 32 ms difference, $P = 0.195$), although the direction and pattern of inspection times mirrors the first two experiments. Thus, picture-inspection times were facilitated when the objects were presented in congruent colors, and inhibited when presented in incongruent colors. These results demonstrate that participants represented the color of diagnostic objects in this semantic task. This provides strong evidence that color routinely facilitates object recognition.

Experiment 3

Experiment 3 was designed to test the degree to which linguistic information could influence, or possibly override, color diagnosticity. One interpretation of color processing suggests that color information is verbal. Thus, color can be seen as a semantic component attached to the understanding of an object (Davidoff and Ostergaard 1988). If color information is largely verbal, linguistically manipulating color should influence processing of color diagnostic objects. In contrast, if the color of HCD objects is intrinsic to the recognition and representation of those objects, then it should be difficult to manipulate the latency pattern obtained in Experiments 1 and 2.

In Experiment 3, participants read *pairs* of related sentences. The first sentence provided a linguistic context, either color appropriate (e.g., After Fred had finished carving the Halloween pumpkin, it looked like a scary goblin.) or color override (e.g., After Fred had finished painting the Halloween pumpkin, it looked like an overgrown lime.). In the second sentence, a picture appeared in the place of the critical noun in color diagnostic, color override, or grayscale (e.g., Fred was going to put the pumpkin on the porch that night.). Where possible, materials and procedures were adopted from the previous experiments.

Method

Participants

Seventy-two undergraduate students participated from the same subject pool as described in Experiment 1.

Materials

The materials in Experiment 3 were identical to Experiment 2 with one exception. To create incongruent but appropriate colored items, some incongruent items had to be re-colored (e.g., a formerly teal pumpkin was made green to fit with the context of the override manipulation). Sentence pairs were created that mentioned experimental objects and the mentioned object words (critical noun) were replaced with the picture of the object.

Ninety-six rebus sentence pairs were created: 24 experimental and 72 filler. The second sentence of each pair included a picture of a color-diagnostic object in one of three color conditions (congruent, neutral, or incongruent). Forty-eight of the filler sentence pairs were nonsensical. The remaining sentences were sensible (i.e., all the experimental sentence pairs and 24 filler sentence pairs).

Design and procedure

The design was similar to Experiment 2, a sensibility-judgment task was used (i.e., participants judged whether each sentence pair made sense or not). Participants read each sentence one word (or picture) at a time in a self-paced manner and indicated whether the sentence pairs made sense or not by pressing the ‘Y’ or ‘N’ labeled keys on the keyboard.

Design and analyses

Picture-inspection times were screened such that unusually long times (i.e., responses exceeding 2 s) were first removed, followed by 2 standard deviation cutoff from the overall condition mean in the respective conditions. Overall accuracy was high: 95%. Outlier removal procedures resulted in the elimination of 7.7% the data. The remaining inspection times were submitted to a 2 (linguistic context: override vs. diagnostic) $\times$ 3 (picture type: Congruent vs. Neutral vs. Incongruent) $\times$ 6 (List 1 vs. List 2 vs. List 3 vs. List 4 vs. List 5 vs. List 6) mixed factor ANOVA with List as a between-subjects variable.

Results and discussion

Analyses revealed significant main effects of the color and sentence manipulations upon picture inspection times [F_1 $(2, 132) = 8.68$, $MSe = 121591$, $P < 0.01$; F_2 $(1, 66) = 25$, $MSe = 304379$, $P < 0.01$]. Analyses did not reveal any significant list effects or any interactions. Mean inspection time for color congruent objects, neutral objects, and color incongruent objects followed our earlier pattern of results: 539, 566, and 597 ms, respectively. All differences were significant (P’s < 0.05), with one minor exception. The P-value obtained for the test between color congruent and neutral objects was 0.056. Mean picture inspection times also differed with regard to the sentence condition (linguistically override vs. diagnostic). Mean inspection times were 594 ms for the linguistic override condition and 541 for the linguistic diagnostic condition

($P < 0.05$). Thus, pictures were “read” more slowly in the linguistic override condition but this difference was uniform across the various color manipulations (i.e., there was no evidence for a sentence by color interaction).

These results mirror our earlier experiments. Picture-inspection times were facilitated by presenting the objects in congruent colors and hindered when presented in incongruent colors. The results are also suggestive that color of HCD objects is an intrinsic property of those objects because providing linguistic, semantic context failed to influence processing of those objects.

General discussion

Our findings demonstrate that color influences object naming, the visualization of objects (as indicated by the verification results), and in an object recognition task in which the occurrence of pictures was (ostensibly) incidental to the task and relatively unpredictable. Specifically, Experiment 1a demonstrated an advantage for naming color diagnostic objects that were congruently colored than when rendered in grayscale or a mismatching color. Experiment 1b demonstrated that verification decision speed from a word to its picture was facilitated when the picture was congruently colored than when rendered in grayscale or a mismatching color. Experiments 2 and 3 demonstrated that picture “reading” in a rebus paradigm was facilitated when the picture was congruently colored than when rendered in grayscale or mismatching color. Figure 2 presents a summary of reaction time data across all our experiments.

Collectively, the findings provide further support for the role of surface information in object recognition. Although shape is certainly the primary route to object recognition, our results are consistent with the review by Tanaka et al. (2001) of color effects. If, according to edge-based accounts, color information merely provides information about shape, then an advantage should have been found for our grayscale images (i.e., because these images provided greater contrast against a white background). This pattern was never obtained. The reaction times for the neutral condition were always situated between the congruent and incongruent conditions across experiments (see Fig. 2) and is an important indicator that color information was not simply used to extract edge information.

Previous research demonstrates a rapid interaction between language and visual representations (e.g., Potter et al. 1986; Stanfield and Zwaan 2001; Tanenhaus et al. 1995; Spivey et al. 2001; Zwaan et al. 2002, 2004). However, our results indicate that there may be limits to the extent that linguistic information can influence object representation. Linguistic context, describing changes in

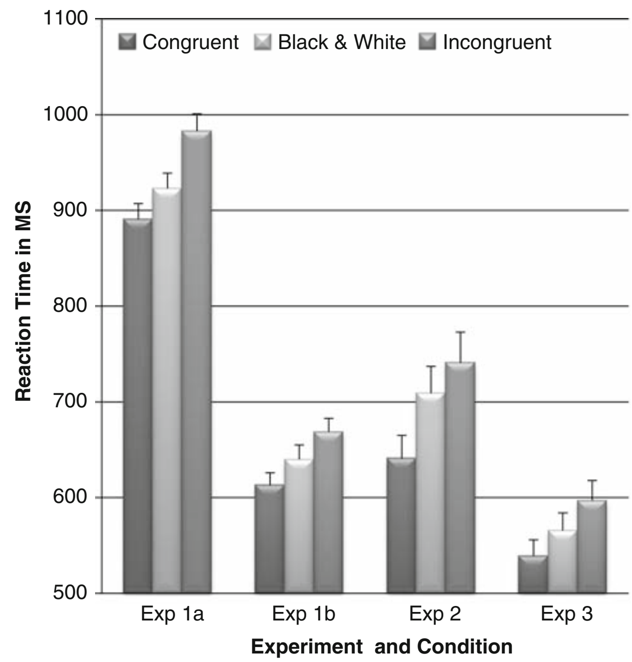

Fig. 2 Mean reaction time in milliseconds for Experiments 1a–3 as a function of color condition, (+SE)

the color of HCD objects, did not facilitate the recognition of those objects. Considering that our sentence override manipulation was specifically aimed at influencing the verbal level, we find it unlikely that object color is mainly represented at a verbal level. Alternatively, Barsalou et al. (2008) argue that the processing of linguistic information can take several seconds before a simulation could have an effect upon behavior. It is possible that our linguistic manipulation did have an effect, but further downstream in the simulation process than the presentation of our picture.

In summary, edge-based accounts of object recognition are parsimonious but are not sufficient to account for perception of HCD objects. The cognitive system has evolved to separate brightness, depth, color, and movement information, and these systems have been explored independently (Livingston and Hubel 1987). However, object recognition processes appear to be more flexible than simply relying on the extraction of shape through brightness, depth, color, and movement. Our results support the conclusion that the processes underlying object recognition and representation can utilize specific color information. Continued study of the influence of color information on object representations will enhance our understanding of the interactive influence of perceptual and cognitive systems.

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Appendix

See appendix table 1

Table 1 color diagnostic stimuli

Baseball mitt
Cigar
Coffee beans
Football
Potato
Teddy bear
Artichoke
Asparagus
Broccoli
Celery
Lime
Beans
Apple
Fire truck
Ladybug
Stop sign
Strawberry
Tomato
Basketball
Cantaloupe
Carrot
Pumpkin
School bus
Traffic cone

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