

# Colorless Green Ideas (Can) Prime Furiously

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## Abstract

That similar words can prime one another is not news. However, this phenomenon can be exploited to make inferences about the organization of conceptual representations. What types of similarity matter? Although there is evidence that similarity of function, shape, and even manner of manipulation is reflected in semantic memory, evidence for organization on the basis of color similarity is sparse. This lack of evidence is surprising: Intuition suggests that color is a prominent feature of many object concepts. The research reported here clarifies this puzzle and illustrates the dynamic nature of conceptual representations. Our research demonstrates color-based priming (e.g., “emerald” primes “cucumber”) in participants who completed a Stroop color-naming task before a priming task. Notably, the size of the Stroop effect predicted the size of the priming effect. When the order of tasks was reversed, priming effects were eliminated. By demonstrating that both extrinsic and intrinsic factors can influence conceptual activation, our findings have implications for theories of semantic memory.

## Keywords

semantic representations, semantic features, semantic attributes, priming, attention, context, color, individual differences, embodied cognition, semantic memory, word recognition

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If you are searching your refrigerator for a cucumber, its color (green) is a useful feature. In contrast, color is less relevant to the task of slicing the cucumber. Does the salience of color in the search context make the cucumber, in a sense, more similar to other green objects than it would be in a slicing context? That is, do sets of “similar” objects change as a function of which properties are contextually relevant? And after you have found the cucumber, does its color remain salient even when color is no longer important to the task? In the research reported here, we explored whether conceptual activation (i.e., the activation of properties of objects) is influenced by contextual relevance. We also investigated individual differences in conceptual activation.

The meanings (or representations) of objects have been characterized as patterns of activations that are distributed across semantic features (e.g., Masson, 1995). One consequence of a distributed architecture is that relationships among concepts can be captured via overlapping patterns. Another is that attention can be focused on specific (e.g., contextually relevant) properties of a representation (e.g., a person’s attention can be focused on greenness while he or she searches for a cucumber). The extent to which an object concept activates a related concept may thus depend on both attention to relevant properties and the extent to which those properties are shared by the two concepts.

Behavioral evidence in support of representational overlap has come primarily from semantic-priming studies demonstrating that the word *cucumber*, for example, primes conceptually related words, such as *mushroom* (e.g., Fischler, 1977). Such studies have also demonstrated that words for perceptually related objects can prime one another. For example, *cherry* primes *ball* because the two objects are similar in shape (Schreuder, Flores D’Arcais, & Glazenborg, 1984; Taylor, 2005), and *piano* primes *typewriter* because of the similar ways in which people’s fingers move over the two objects (Myung, Blumstein, & Sedivy, 2006). However, research has yielded no clear evidence for an analogous effect of color (Huettig & Altmann, 2011; cf. Taylor & Heindel, 2004).

Why might color be different? One possibility is that color is less essential to knowledge of an object than are other features, and that color is therefore encoded only for objects for which it is diagnostic (i.e., when it has high information value, as in the case of a fire engine; Tanaka & Presnell, 1999; but cf. Rossion & Pourtois, 2004) or only for objects (e.g., lemons) that need to be distinguished from similarly shaped objects

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(e.g., limes; Price & Humphreys, 1989). But even these objects can usually be recognized in black and white, which suggests that color may be less important than other features (e.g., Biederman, 1987). Thus, color may constitute only a small portion of an object's representation, which may explain why evidence for representational overlap on the basis of color has been scarce (cf. Joseph, 1997). If color is a relatively minor feature of objects' representations, however, it may be of use in exploring the extent to which conceptual representations are dynamically affected by context: Color may be more sensitive to context than are other, more important features (e.g., function), which, because of their importance, may be less variable in the degree to which they are activated.

In the research reported here, we used semantic priming to assess whether representations of objects that share color partially activate each other, and, if so, whether this activation is dependent on context. We manipulated the extent to which participants' attention was focused on color by having them complete a standard Stroop color-naming task either before or after they completed a priming task. This method allowed us to test whether the experience of having recently focused attention on color (in the Stroop task) would influence the degree of color activation in a subsequent priming task. We also tested whether individual differences in susceptibility to Stroop interference predicted individual differences in color priming.

## Method

### Participants

One hundred twenty participants (66 female, 54 male) from the University of Pennsylvania community participated in return for either \$10 per hour or course credit. All were native English speakers and had normal or corrected-to-normal color vision. Sixty participants performed the Stroop task prior to the priming task. The remaining participants performed the priming task first. Participants performed both tasks on a computer.

### Materials and procedure

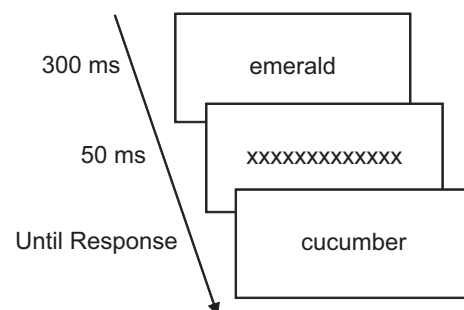
**Stroop task.** For this task, written color words ("red," "yellow," "green," "blue," and "black") in differently colored fonts were presented to participants, who were instructed to press a key (labeled in black ink) that corresponded to each word's font color. Each word remained on the screen until the participant made a response. The Stroop task consisted of 100 trials; the intertrial interval was 500 ms. On half of the trials, the color word and font color were congruent. Trial order was randomized.

**Priming task.** The priming task was a semantic-judgment task in which participants had to determine whether or not target words named animals. The target words referred to

animals on filler trials and nonanimals on critical trials. Each critical target (e.g., *cucumber*) was paired with a color-related prime (e.g., *emerald*) and with a control prime that was unrelated in color (e.g., *pendant*). All words were presented in black type. The color-related and control primes for each critical target were matched for animacy, word frequency, number of letters, number of syllables, and similarity, as computed via latent semantic analysis. In a norming study, a group of 30 participants who did not participate in the main experiment rated the critical prime-target pairs using a scale from 1 (*very unlikely to be the same color*) to 7 (*very likely to be the same color*). Results showed that the objects in color-related pairs were judged as more likely to be the same color ( $M = 5.9$ ) than the objects in control pairs ( $M = 2.3$ ). Another group of 30 participants in a second norming study rated the importance of color in recognizing the objects within each critical pair, using a scale from 1 (*not important*) to 7 (*very important*). Results showed that they rated color as being more important for recognizing both the targets and the color-related primes ( $M = 4.9$ ) than for recognizing the control primes ( $M = 2.8$ ). For more details about the norming studies and to view the full list of stimuli, see the Supplemental Material available online.

Critical stimuli were divided into two counterbalanced lists, each of which contained 60 critical prime-target pairs (30 critical targets paired with a color-related prime and 30 critical targets paired with a control prime) and 60 filler prime-target pairs (the same filler stimuli were included on both lists). Each participant was assigned one list; prime-target pairs were presented in a fixed random order. The priming task consisted of 122 trials, beginning with 2 practice trials and 6 filler trials.

On each trial, participants were presented with a prime for 300 ms, a mask for 50 ms, and then the target. The target remained on-screen until participants responded by pressing the "A" key, to indicate that the target was an animal, or the "I" key, to indicate that the target was not an animal (Fig. 1). On 12% of the trials, a prompt asking whether the prime was an animal appeared after participants had made their response; this prompt was intended to ensure that participants would attend to the primes. See the Supplemental Material for the priming-task instructions.



**Fig. 1.** Stimuli and trial structure for the priming task. Participants were presented with a prime for 300 ms, a mask for 50 ms, and then a target word, which remained on-screen until they responded by indicating whether the target word was the name of an animal.

**Posttest questionnaire.** After participants had finished both tasks, they completed a posttest questionnaire asking them what they thought the experiment was about. Two participants noticed that the prime and target occasionally referred to things of the same color. The pattern of results was unchanged when data for these participants were removed from analysis. See the Supplemental Material for additional details about the posttest questionnaire.

## Results

An analysis of variance (ANOVA) on response times (RTs) for correct responses in the Stroop task (Fig. 2) revealed a significant main effect of congruency,  $F(1, 118) = 189.8, p < .001$ ; no effect of task order; and no interaction between congruency and task order (both  $F_s < 1$ ). An ANOVA on error rates in the Stroop task yielded the same pattern of results.

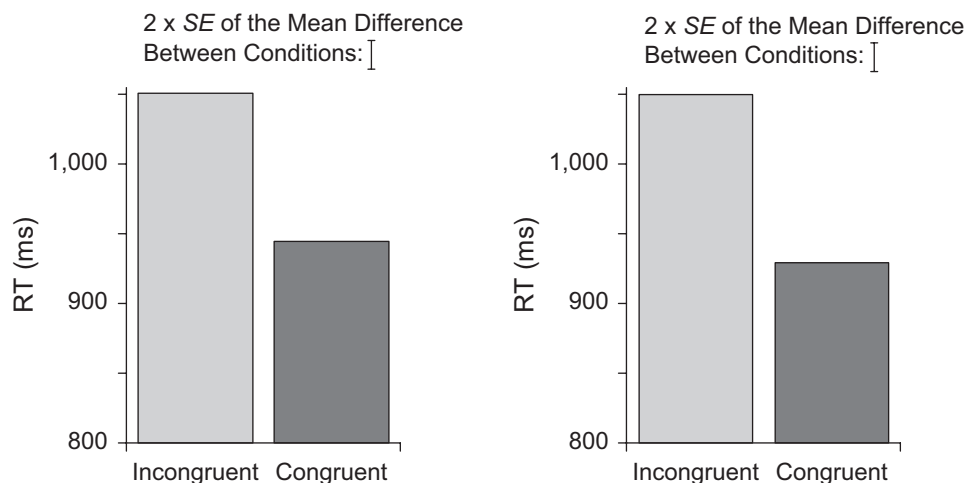
An ANOVA on RTs for correct responses on critical trials in the priming task (Fig. 3) revealed that there was not a significant main effect of color relatedness,  $F_1(1, 118) = 3.6, p = .06$ , and  $F_2(1, 58)^1 = 1.2, p = .28$ . The effect of task order was not significant by subjects ( $F_1 < 1$ ), but it was significant by items,  $F_2(1, 58) = 15.7, p < .01$ . Critically, the interaction between color relatedness and task order was significant both by subjects,  $F_1(1, 118) = 3.9, p = .05$ , and by items,  $F_2(1, 58) = 3.9, p = .05$ . Planned comparisons showed that for participants who performed the Stroop task first, responses were faster for color-related prime-target pairs than for control pairs,  $t_1(59) = 2.6, p = .01$ , although the difference was only marginally significant by items,  $t_2(58) = 1.7, p = .09$ . For participants who performed the priming task first, there was no difference between RTs for color-related pairs and RTs for control pairs,  $t_1(59) = -0.1, p = .96$ , and  $t_2(58) = 0.0, p = .98$ .

An ANOVA on accuracy in the priming task yielded the same pattern of results. There was no main effect of relatedness,  $F_1(1, 118) = 2.4, p = .12$ , and  $F_2(1, 58) = 1.7, p = .20$ , or task order,  $F_1 < 1$ , and  $F_2(1, 58) = 2.0, p = .17$ . However, we again found the critical interaction between relatedness and task order,  $F_1(1, 118) = 4.8, p = .03$ , and  $F_2(1, 58) = 5.3, p = .02$ . Planned comparisons showed that accuracy was greater for color-related trials than for control trials in the Stroop-first order,  $t_1(59) = 2.7, p = .01$ , and  $t_2(58) = 2.2, p = .03$ , but not in the priming-first order,  $t_1(59) = -0.4, p = .67$ , and  $t_2(58) = -0.3, p = .73$ .

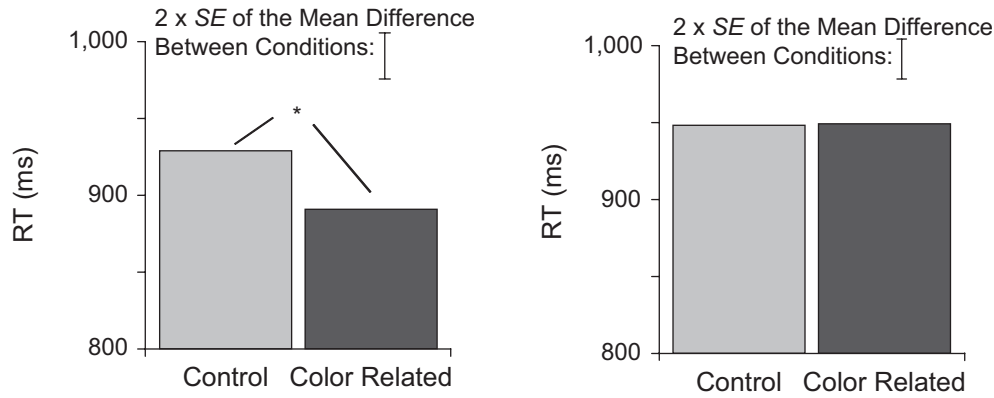
We also tested whether the size of the Stroop interference effect for a given participant (mean RT for incongruent trials – mean RT for congruent trials/mean RT for incongruent trials) predicted the size of that participant's color-priming effect (mean RT for unrelated pairs – mean RT for related pairs/mean RT for unrelated pairs). For participants who performed the Stroop task first, Stroop interference was positively correlated with the color-priming effect,  $r = .38, p = .003$ . However, for participants who performed the priming task first, there was no such correlation,  $r = .04, p = .76$  (Fig. 4). The difference between the correlations was significant,  $z = 1.9, p = .05$ .

## Discussion

Our results show that after participants' attention had been drawn to color via a standard Stroop task, reading the name of an object primed other objects that shared the same diagnostic color—an effect that has not been previously reported. Further, individual participants' susceptibility to Stroop interference predicted the magnitude of this color-priming effect. Notably, color priming occurred despite the fact that color was irrelevant to the priming task (i.e., judging whether words in



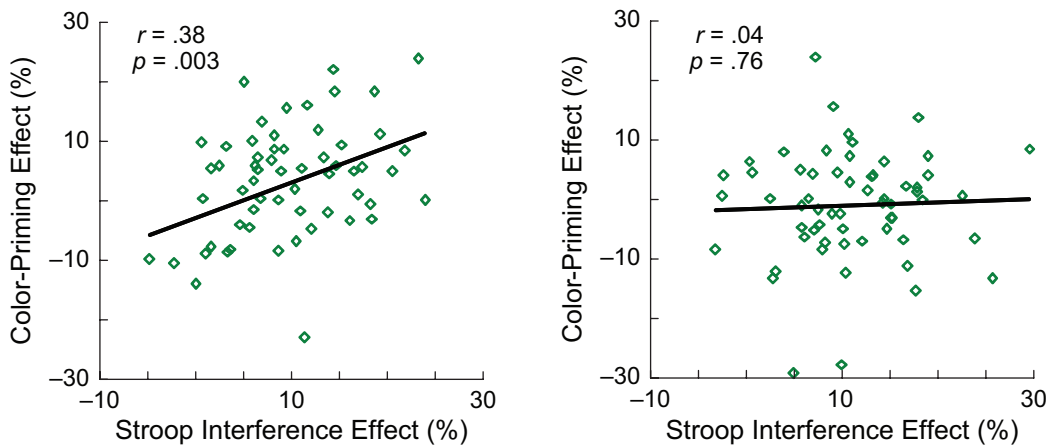
**Fig. 2.** Mean response times (RTs; correct responses only) in the Stroop task as a function of congruency between color names and font colors. The left panel shows results for participants who performed the Stroop task before the priming task, and the right panel shows results for participants who performed the Stroop task after the priming task.



**Fig. 3.** Mean response times (RTs; correct responses only) on critical trials in the priming task as a function of color relatedness between primes and targets. The left panel shows results for participants who performed the priming task after the Stroop task; the right panel shows results for participants who performed the priming task before the Stroop task. The asterisk indicates a significant difference between RTs for color-related and control prime-target pairs ( $p < .05$ ).

black type were names for animals). In contrast, when attention had not been drawn to color, no priming effects were observed. Hence, the extent to which color information about an object is activated appears to depend not only on long-term, object-related factors (i.e., whether color is generally relevant for identifying the object; see Tanaka & Presnell, 1999), but also on short-term, context-related factors (i.e., whether attention was recently focused on color). This context-dependent activation of color has parallels at the cellular level: Recordings from inferotemporal neurons in monkeys have shown that in some cells, the firing rate in response to color stimuli increases when color is task relevant (Fuster & Jervey, 1981). We found further that the influence of context-related factors appears to be dependent on individual difference factors (which we return to later in this discussion).

Previous work has demonstrated that altering the immediate context in which a word is presented can influence which aspects of its representation are activated. For example, if you hear “cucumber” mentioned in a sentence about eating salad, you might access the crunchiness of cucumbers (cf. Barclay, Bransford, Franks, McCarrell, & Nitsch, 1974), and sentence context can also influence the activation of information about cucumbers’ color (Connell, 2007; Connell & Lynott, 2009). Similarly, immediate context can influence the kind of motor information that is activated by a word (van Dam, Rueschmeyer, Lindemann, & Bekkering, 2010). However, to our knowledge, only one prior study has demonstrated that *nonimmediate* but recent experience can “linger” enough to influence the activation of semantic features in a subsequent task: Pecher, Zeelenberg, and Raaijmakers (1998) found that



**Fig. 4.** Scatter plots (with best-fitting regression lines) showing the correlations between the Stroop interference effect and the color-priming effect. The left panel shows results for participants who performed the priming task after the Stroop task; the right panel shows results for participants who performed the priming task before the Stroop task.

semantic priming on the basis of shape similarity is enhanced if, prior to a priming task, participants make perceptual judgments about the objects to which the to-be-primed words refer. Our work extends this finding to color-based priming, but, more important, it also demonstrates that the priming effect is general: It was neither specific to objects (only color names were used in the Stroop task) nor restricted to the colors presented in the Stroop task—the correlation between the Stroop effect and the priming effect was the same for items whose colors were and were not included in the Stroop task ( $r = .31$  in both cases). Our findings thus indicate that general attention to color is sufficient to alter subsequent processing.

It remains to be determined whether the influence of recent experience can generalize across objects for features besides color. For example, after a person has chopped cucumbers (a task that focuses attention on manual action), would *piano* activate *typewriter* (as shown by Myung et al., 2006) more strongly than usual? Or is color uniquely sensitive to context because it is rarely essential for the identification of objects and thus benefits more than other features from contextual enhancement (for discussion, see Barsalou, 1982)?

In addition to demonstrating color priming and its dependence on context, we observed a positive correlation between Stroop interference and color-priming effects among participants who performed the Stroop task prior to the priming task. What might have driven this correlation? One possibility concerns individual differences in selective attention: The ability to selectively attend to a word's font color (while ignoring its meaning) in the Stroop task may require a generally high capacity for selective attention, which, in the priming task, could have been manifested as enhanced selective attention to features most relevant for judging animal status. Such selective attention would have resulted in less activation of, and hence less priming from, the object's other features (e.g., color). If true, this account would suggest that Stroop performance (or other measures of cognitive control) may correlate with semantic-priming effects in general, rather than color priming specifically (cf. Kiefer, Ahlegian, & Spitzer, 2005).

Another possibility is that the correlation between Stroop interference and color priming reflected individual differences in the content of representations: Information-processing preferences can produce differences in the degree to which people typically attend to or perceive color (Hsu, Kraemer, Oliver, Schlichting, & Thompson-Schill, 2011). Such differences should lead to differences in how strongly color is encoded, which would influence the strength of the associations between color and both color words (e.g., *green*) and the names of objects (e.g., *cucumber*). Stronger associations would cause more interference from color words in the Stroop task and more activation of color information by object names in the priming task.

Future work should explore whether the correlation observed in our experiment reflects individual variability in the capacity for selective attention in general or in attention to

color specifically. In either case, context must moderate such individual differences: When the Stroop task was performed after the priming task, no color-priming effect (and thus no correlation between Stroop interference and color priming) was observed.

By showing that objects that are the same color have overlapping representations and that attention can be focused on specific aspects of an object's representation, our findings provide support for distributed models of semantic memory (e.g., Masson, 1995; McRae, de Sa, & Seidenberg, 1997; see also Schyns, Goldstone, & Thibaut, 1998). Further, because color is a perceptual feature, our finding that the representations of color-related objects activate one another supports a critical prediction of *sensorimotor-based* distributed models (e.g., Barsalou, 1999; Warrington & McCarthy, 1987). These models assume that semantic information about an object is represented in the neural substrate invoked when the object is perceived or interacted with, and recent functional MRI studies suggest that this is true for color-related semantic information (Hsu et al., 2011; Simmons et al., 2007). Thus, sensorimotor-based models require that objects with shared perceptual features, such as color, have overlapping representations, but until now, priming on the basis of shared color has not been reported.

Traditionally, in the study of semantic representations (and, in fact, in cognitive psychology more broadly), it has been assumed that only effects that can be demonstrated across a variety of contexts should be considered informative regarding the architecture of the system being investigated. Yet our findings show that the prominence of a concept's features, rather than being fixed, can change from one context to another and, within a given context, from one person to another. We contend that instead of being mere "noise," this variability is an important consequence of semantic memory's distributed architecture: This architecture allows attention to be focused on whichever properties of a representation are contextually relevant, rendering conceptual representations dynamic (Hoenig, Sim, Bochev, Herrnberger, & Kiefer, 2008; for discussion, see Humphreys & Forde, 2001; Kiefer & Martens, 2010; and Spivey, 2007).

For decades, semantic-priming effects have been a major source of evidence in the study of semantic knowledge. Our research indicates that both the interpretation of semantic-priming effects and the understanding of conceptual representations must take into account the influence of context and individual susceptibility to context. This context does not have to be immediate: It can include the lingering traces of recent experience. Colorless green ideas *can* prime—in the right context, for the right people.

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## Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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## Supplemental Material

Additional supporting information may be found at <http://pss.sagepub.com/content/by/supplemental-data>

## Note

1. RTs and error rates were more than 3 standard deviations higher for one item than they were for the rest of the items; this item was therefore excluded from analysis.

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