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## Colorless green ideas (can) prime furiously

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### Abstract

That similar words can prime one another isn't news. However, recently this phenomenon has been exploited to make inferences about conceptual representations. What types of similarity matter? While there is evidence that similarity in function, shape, and even manipulation figure in the organization of semantic memory, evidence for color similarity is sparse. This is surprising: intuition suggests that color is a prominent feature of many concepts. We report an experiment that clarifies this puzzle and illustrates the dynamic nature of conceptual representations. We report color priming (e.g., the word *emerald* primes the word *cucumber*) in subjects who have previously completed a color-Stroop task. Notably, the size of the Stroop effect predicts the size of the priming effect across subjects. When the order of tasks is reversed, priming is eliminated. By highlighting that extrinsic and intrinsic factors can both influence conceptual activation, these findings have implications for theories of semantic memory.

### Keywords

semantic representations; semantic features; semantic attributes; context; color; individual differences; attention; embodied cognition

### Introduction

If you are searching your refrigerator to find a cucumber, its color (green) is a useful feature. In contrast, color is less relevant while slicing the cucumber. Does the salience of color in the search context make cucumbers, in a sense, more similar to other green objects than they are in a slicing context? That is, does the set of “similar” objects change as a function of which properties are contextually relevant? How about after you've found the cucumber—does color “linger”, remaining salient even though it's no longer important to the task? Here we explore whether conceptual activation (i.e., which object properties are activated when) is influenced by task relevance. We also explore individual differences in this conceptual activation.

The meaning of an object is often characterized as a pattern that is distributed across semantic features (e.g., Masson, 1995). One consequence of this 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., attention can be focused on greenness when searching for a cucumber). Thus the extent to which an object concept activates a related concept may depend on both attention to relevant properties, and on the extent to which those properties are shared between the concepts.

Behavioral evidence in support of representational overlap comes primarily from semantic priming studies demonstrating that the word cucumber, for example, primes conceptually related things like mushrooms (e.g., Fischler, 1977). Such studies have also demonstrated priming for perceptual relationships. For example, cherry primes ball, due to similarity in shape (Schreuder et al., 1986; Taylor 2005), and piano primes typewriter, due to similarity in the way the fingers move over each (Myung et al., 2005). Interestingly, however, there has been little, if any, evidence of an analogous effect for color (Huettig & Altmann, 2010; cf. Taylor & Heindel, 2004).

Why might color be different? One possibility is that color is less essential to object knowledge than other features, and is only encoded when it is “diagnostic” – i.e., has high information value (Tanaka & Presnell, 1999; but cf. Rossion & Pourtois, 2004), or only for objects that need to be recognized in the context of similarly shaped objects (Price & Humphreys, 1989). And even these objects can usually be recognized in black and white, suggesting that color may still be less important than other features (e.g., Biederman, 1987). If true, color may constitute only a small portion of an object’s representation. This may explain why evidence of conceptual overlap based on color has been scarce (cf. Joseph, 1997). It may also make color a good case for exploring the extent to which conceptual representations can be dynamically affected by context: Color may be more sensitive to context than other, more important features (e.g., function) which, because of their importance, may be less variable in the degree to which they become active.

In the current work, we used semantic priming to assess whether objects that share color partially activate each other, and if so, whether this activation is context-dependent. We manipulated the extent to which attention is focused on color by having participants complete a standard color Stroop task before or after the priming task. This allowed us to test whether the experience of having recently focused attention on color (in the Stroop task) influences 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. We show that: 1) Rather than having a fixed activation profile, conceptual representations can be dynamically affected by context, 2) Contextually-modulated attention to color varies across individuals, and importantly, 3) Context’s influence can “linger” beyond when it is relevant.

## Methods

### Participants

120 participants (66 female) from the University of Pennsylvania community received \$10/hour or course credit for participating. All were native English speakers and had normal or

corrected-to-normal color vision. 60 participants performed the Stroop task prior to the priming task (“Stroop first” order). The remainder performed the priming task first (“priming first” order).

## Materials & Procedure

**Stroop task**—Participants saw written color words (red, yellow, green, blue, black) and were instructed to press the key (labeled in black ink) that corresponded to the font color. The word remained on the screen until the response. The inter-trial interval was 500ms. There were 100 trials. In half, the word and font color were congruent. Trial order was randomized.

**Animal judgment task**—We created 60 color-related prime-target pairs (e.g., *emerald-cucumber*), and 60 control pairs using the same target but a prime unrelated in color (e.g., *pendant-cucumber*). The task was a semantic judgment (animal or not?). No critical targets were animals. Related and control primes were matched for animacy, frequency, number of letters, number of syllables, and similarity as computed via Latent Semantic Analysis. Two separate groups of 30 participants (who did not participate in the priming study) confirmed via 1–7 ratings that color-related pairs were more likely to be the same color ( $M=5.9$ ) than control pairs ( $M=2.3$ ), and that color was more important for recognizing objects constituting color-related pairs ( $M=4.9$ ) than for recognizing control primes ( $M=2.8$ ).

Critical stimuli were divided into two counterbalanced lists containing 30 color-related, 30 control, and 60 filler trials (all fillers had animal targets, e.g., *pants-worm*). Each subject saw one list, in a fixed random order. There were 2 practice and 6 filler trials at the beginning of the experiment.

Participants were presented with the prime (300ms), a mask (50ms) and then the target until they responded, pressing “A” or “I” respectively if the target was/was not an animal (Figure 1). To ensure that participants attended to the prime, in 12% of trials, after their response, a prompt appeared asking if the prime was an animal. A post-test questionnaire asked what participants thought the experiment was about. Two noticed that the 1<sup>st</sup> and 2<sup>nd</sup> words occasionally referred to things of the same color. The pattern was unchanged with these participants removed. See supplementary materials for additional details and a full list of stimuli.

## Results

For the Stroop task (Figure 2), ANOVA on reaction times (correct only) 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 order (both  $F_s < 1$ ). The pattern for accuracy was the same.

For the priming task (Figure 3), ANOVA on reaction times (correct only) revealed that across both orders there was a non-significant main effect of relatedness  $F_1(1,118) = 3.6, p = .06, F_2(1,58^1) = 1.2, p = .28$ . The effect of task order was not significant by subjects ( $F_1 < 1$ ), but was by items  $F_2(1,58) = 15.7, p < .01$ . Critically, the interaction between

relatedness and task order was significant by both subjects  $F_1(1,118) = 3.9, p = .05$ , and items  $F_2(1,58) = 3.9, p = .05$ . Planned comparisons showed that in the Stroop-first order, responses were faster in color-related than control trials,  $t_1(59) = 2.6, p = .01$ , although the difference was only marginally significant by items  $t_2(58) = 1.7, p = .09$ . In the priming-first order, there was no difference between color-related and control trials  $t_1(59) = -0.1, p = .96$ ,  $t_2(58) = 0.0, p = .98$ .

Accuracy in the priming task followed the same pattern: No main effect of relatedness  $F_1(1,118) = 2.4, p = .12$ ,  $F_2(1,58) = 1.7, p = .20$ , or task order,  $F_1 < 1$ ,  $F_2(1,58) = 2.0, p = .17$ . However, the critical interaction between relatedness and task order was again present,  $F_1(1,118) = 4.8, p = .03$ ,  $F_2(1,58) = 5.3, p = .02$ . Planned comparisons showed that color-related trials were responded to more accurately in the Stroop-first order,  $t_1(59) = 2.7, p = .01$ ,  $t_2(58) = 2.2, p = .03$ , but not in the priming-first order,  $t_1(59) = -0.4, p = .67$ ,  $t_2(58) = -0.3, p = .73$ .

We also tested whether the size of the Stroop interference effect for a given participant (RT incongruent – RT congruent / RT incongruent) was predictive of the size of the color priming effect (RT unrelated – RT related / RT unrelated). We found that in the Stroop-first order, Stroop interference was positively correlated with color priming  $r = .38, p = .003$ . However, when the order was reversed, there was no correlation  $r = .04, p = .76$  (Figure 4). The difference between the correlations was significant,  $z = 1.9, p = .05$ .

## Discussion

When attention has first been drawn to color via a standard Stroop task, reading the name of an object primes other objects that share the same diagnostic color – an effect that has not been previously reported. Further, an individual's susceptibility to Stroop interference predicted the amount of priming. Importantly, priming occurred despite the fact that color was irrelevant to the immediate task—animal judgment of written words that were presented in black type. In contrast, when attention was not previously drawn to color, no priming was 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., is color relevant in general for the identification of this object?) as shown by Tanaka & Presnell (1999), but also on shorter-term, context-related factors (i.e., has attention been recently focused on color?). There are parallels to context-dependent activation of color at the cellular level: Recordings from inferotemporal neurons in monkeys showed that in some cells, firing rate to color stimuli depended upon whether color was task-relevant (Fuster & Jervey, 1981). We find further that the influence of these context-related factors appears to be dependent on individual factors (which we return to below).

Previous work has demonstrated that altering the *immediate* context in which a word is presented can influence which aspects of its representation are active. For example, if a cucumber is mentioned in a sentence about eating it, you might access how crunchy it is (cf. Barclay et al., 1974); and sentence context can influence the activation of its color (Connell,

<sup>1</sup>One item elicited response times and errors more than 3SD higher than the rest and was excluded from analysis.

2007; Connell & Lynott, 2009). Similarly, immediate context can influence the kind of motor information that is activated by a word (van Dam, Rueschemeyer, Lindemann & Bekkering, 2010). However, to our knowledge, only one prior study has demonstrated that *non-immediate*, but recent experience can “linger” enough to influence the activation of semantic features in a subsequent task: Semantic priming based on shape similarity is enhanced if, prior to the priming task, participants first make perceptual judgments about the objects to which the to-be-primed words refer (Pecher et al., 1998). The present work extends this finding to color but importantly, also demonstrates that the effect is general: it is neither object-specific (only color names were used in the Stroop task), nor isolated to the colors presented in the Stroop task—the correlation between Stroop interference and priming was the same for items whose colors and were or were not included in the Stroop task ( $r=.31$  in both cases). Thus, *general* attention to color is sufficient to alter subsequent processing. An open question is whether the influence of recent experience can generalize across objects for features besides color. For example, after chopping cucumbers (a task that focuses attention on manual action), would *piano* activate *typewriter* (as shown by Myung et al., 2005) more than usual? Or is color uniquely sensitive to context because it is rarely essential for object identification, 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 also observed that when the Stroop task was performed prior to the priming task there was a positive correlation between participants’ Stroop incongruency and color priming effects. What might drive this correlation? One possibility concerns individual differences in selective attention: If the ability to selectively attend to a word’s ink color (while ignoring its meaning) in the Stroop task is due to a generally high capacity for selective attention, this could manifest, in the priming task, as selective attention to features most relevant for judging animal status. This would result in less activation of, and hence less priming from, the object’s other features (like color). Interestingly, this kind of 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 reflects 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 et al., 2011). This should lead to differences in how strongly color is encoded, which would influence how strongly associated color becomes both with names of color words (e.g., green) and with names of objects (e.g., cucumber). Strong associations would cause more interference from color words in the Stroop task, and more activation of color from object names in the priming task.

Future work can explore whether the observed correlation reflects individual variability in a general capacity to selectively attend, or in attention to color specifically. In either case though, context must moderate these individual differences—for when the Stroop task was performed *after* the priming task, no correlation (and also no priming) was observed.

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

Traditionally, when studying 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 with regards to the architecture of the system being investigated. Yet our findings show that rather than being fixed, the prominence of a concept's features can change from one context to another, and *within* a given context, from one person to another. We contend that instead of being “nuisance noise”, this variability is an important consequence of semantic memory's distributed architecture—wherein because attention can be focused on specific (e.g., contextually relevant) properties of a representation, conceptual representations are dynamic (Hoenig et al., 2008; see Humphreys & Forde, 2001; Spivey, 2007 and Kiefer & Martens, 2010 for discussion).

For decades, semantic priming has been a major source of evidence in the way we think about semantic knowledge. The current work highlights that in both the way we interpret semantic priming, and the way we think of concepts, we must take the influence of context, and individual susceptibility to context, into account; critically, this context does not have to be immediate—it can also include “lingering” traces of recent experience: Colorless green ideas *can* prime—in the right context, for the right people.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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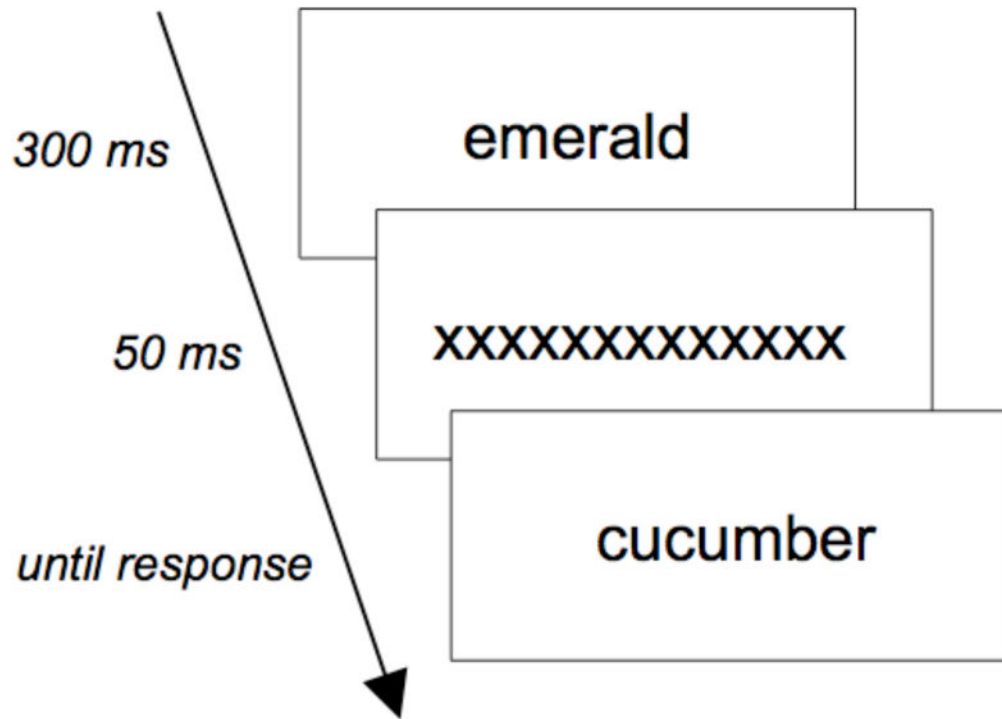
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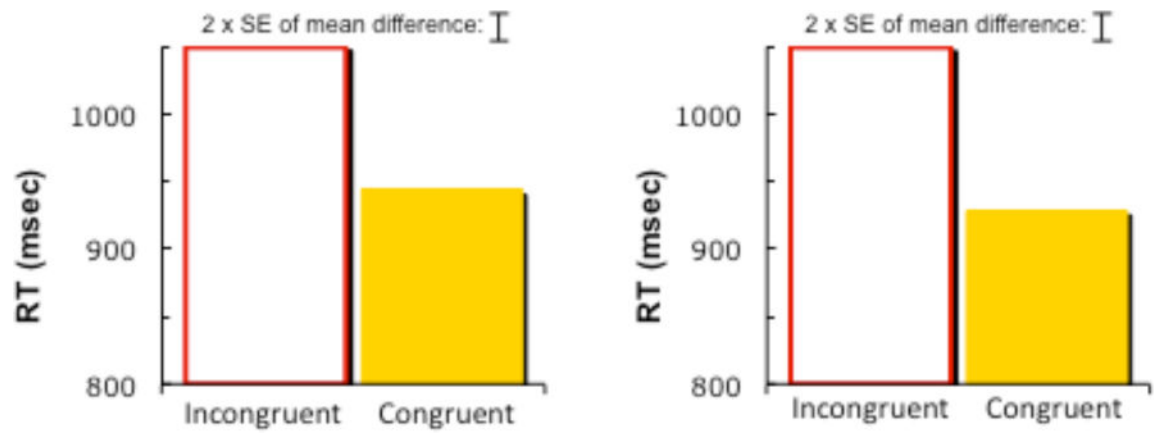
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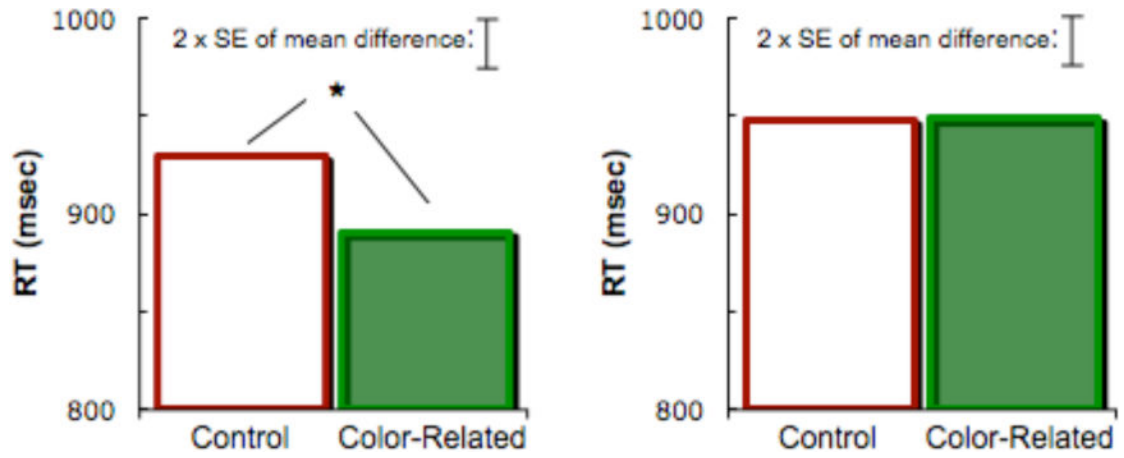




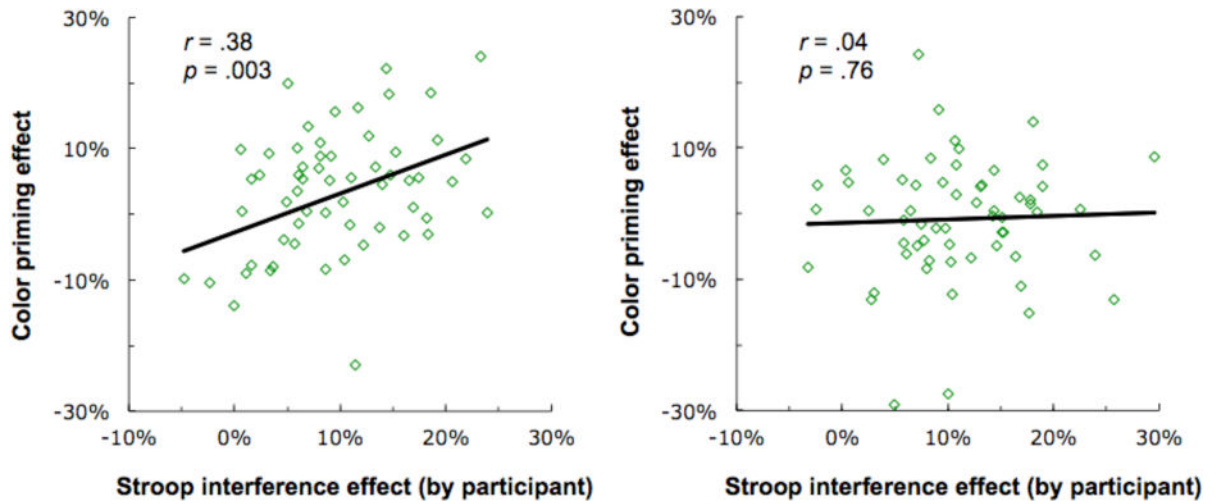
**Figure 1.** Structure of priming task. Participants judged whether the 2<sup>nd</sup> (target) word was an animal.



**Figure 2.** Response times (correct only) in Stroop task when performed before animal judgment (left panel), and when performed after animal judgment (right panel).



**Figure 3.** Response times (correct only) in animal judgment task when performed after Stroop task (left panel), and when performed before Stroop task (right panel).



**Figure 4.** Correlation between congruency effect and priming effect when animal judgment task performed after Stroop (left panel), and when animal judgment task performed before Stroop (right panel).