Is categorical perception really verbally mediated perception?

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Abstract

Recent research has argued that categorization is strongly tied to language processing. For example, language (in the form of verbal category labels) has been shown to influence perceptual discriminations of color (Winawer et al., 2007). However, does this imply that categorical perception is essentially verbally mediated perception? The present study extends recent findings in our lab showing that categorical perception can occur even in the absence of overt labels. In particular, we evaluate the degree to which certain interference tasks (verbal and spatial) reduce the effect of learned categorical perception for complex visual stimuli (faces). Contrary to previous findings with color categories, our results show that a verbal interference task does not disrupt learned categorical perception effects for faces. Our results are interpreted in light of the ongoing debate about the role of language in categorization. In particular, we suggest that at least a sub-set of categorical perception effects may be effectively "language-free". **Keywords:** Perceptual Learning, Categorization, Concept Learning, Language.

Introduction

It is now well-known that the categories we know often influence the things that we perceive. For example, the phoneme categories in the native language of a listener dramatically influence their ability to perceive physical differences between two speech sounds. In particular, differences that span phonemic category boundaries are much more accurately discriminated than differences that fall within the same phonemic category (Liberman, Harris, Hoffman, & Griffith, 1957). This effect, known as Categorical Perception (CP), has been shown for many types of perceptual stimuli, and is known to be influenced by both innate and learned factors (e.g., Harnad, 1987; Goldstone, 1994; see Goldstone & Hendrickson, 2009 for a review).

Given the fact that CP effects are so ubiquitous, it is perhaps surprising that so little is known about how they arise. Theoretical analyses suggest that the very act of associating category labels with items can warp the representations of those items in the service of categorization. For example, Harnad, Hanson, & Lubin (1995) showed through neural network simulations that adding such a label, even without changing the representation space, changed the similarity of item representations in that space in a way consistent with CP effects. However, such simulations simply show how CP might *arise* without explaining the exact psychological factors that may contribute to it in humans.

On the other hand, recent work by Winawer et al. (2007) has argued that the change in representation that produces such a CP effect may be due to the inclusion of a "language-specific" component to the representation of an item in memory. In their study, Winawer and colleagues found that Russian speakers, who have unique words in their language for 'light blue' and 'dark blue,' show a standard CP effect: a higher accuracy for perceptual discriminations of blues that span the light-dark category boundary relative to blues within one category. English speakers, who only use one basic word for blue, did not show a similar CP effect for the same stimuli. Interestingly, the CP between-category advantage was eliminated for the Russian speakers when they were given a verbal interference task (repeating a string of digits) while performing the perceptual discriminations, though the CP effect was preserved if the interference task involved a spatial task (remembering a pattern) instead of a verbal task. From this, Winawer, et al. argue that linguistic processing not only influences the category learning processes, but has an online influence during perceptual discrimination as well (see also Lupyan, 2008).

Somewhat consistent with this viewpoint, learned CP effects are most often found in supervised learning tasks, where feedback about an item's correct category label drives learning to reduce classification error of category labels (Harnad, 1987; Goldstone & Hendrickson, 2009). However, Gureckis and Goldstone (2008) presented an interesting finding which would appear to challenge this view. In their study, a set of morph faces was created with varied along two arbitrary dimensions (Figure 1). Four "clusters" of items were created in the space by withholding a subset of the items from the training phase (the grey stimuli in Figure 1). Two of the clusters were assigned to category "A" and the other two clusters were assigned to category "B" by applying either a vertical or horizontal category boundary. Both before and after category learning participant's ability to make pair-wise discriminations between items was measured. The results showed that discrimination of items within each small cluster was reduced following learning. In addition, discrimination of items across the category boundary was improved (a pattern consistent with the standard CP effect). They also found that discrimination performance was improved between clusters that belonged to the same category. These CP effects were largest in blocks in which performance on the categorization judgment task was highest, suggesting that learning drove both improvements in categorization performance as well as the changes in perceptual discrimination.

The improvement in perceptual discrimination *within* a category (and along the category-irrelevant dimension) would not be predicted if CP was only the result of verbal labeling processes since all of these items share the same label. Instead, it appears to suggest that a non-verbal learning mechanism is engaged during category learning that is sensitive to the internal structure of the categories (e.g., Love, Medin, & Gureckis, 2004). In this study we explore the hypothesis that the effect of this non-verbal learning is not impacted by verbal interference.

In our experiment, we taught participants to categorize the same set of morphed faces that have been previously shown to induce categorical perception effects in Goldstone (1994) and Gureckis & Goldstone (2008). Following the learning phase we had participants make perceptual discriminations between pairs of faces that span both the category and cluster boundaries while performing a set of spatial or verbal interference tasks. Similar to the approach adopted by Winawer, et al, our goal was to assess the impact that verbal interference has on CP of these stimuli relative to a spatial interference task. In light of these previous findings, we predict that verbal interference will disrupt the standard CP effect of improved discrimination across the category-relevant boundary by preventing online linguistic processing while a spatial interference task does not. In contrast, we predict that verbal interference would have little impact on the improved discrimination of items that belongs to different clusters within the same category (since such effects are unlikely to be driven by differences in verbal labeling). In line with previous work, we further predict that these effects will be most pronounced for perceptual discrimination judgments in blocks where categorization performance is most accurate. Our results replicate the effects of previous studies, but we found that the interference tasks had overall little effect on learned CP for our face stimuli.

An Experiment

Method

Participants 172 students at Indiana University participated in partial fulfillment of a course requirement and were assigned into one of two conditions based on which dimension (1 or 2 in Figure 1) was relevant for

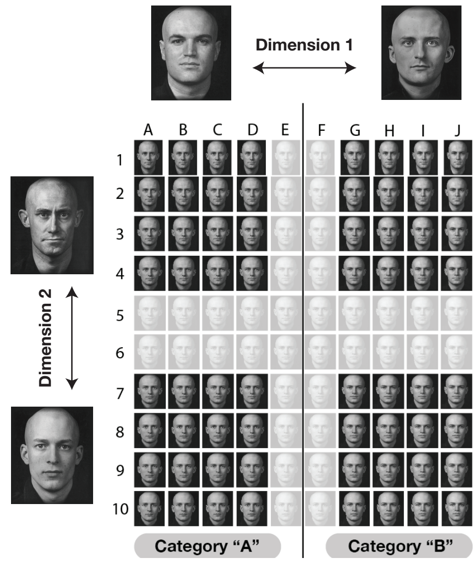

Figure 1: Stimuli varied along two arbitrary dimensions (1 and 2) forming a 10-by-10 grid of blended faces. The light grey stimuli were not included in category learning, introducing a source of within-category structure (two clusters of faces within each category). The vertical line between columns E and F shows an example category boundary used during category learning (the other category boundary was a horizontal line between rows 5 and 6).

categorization (87 had dimension 2, and 85 had dimension 1). 61 participants were excluded who did not perform significantly above chance on either categorization or discrimination trials with no interference task (the threshold used for both tasks was 0.52, the upper threshold of a 95% confidence interval based on a binomial distribution centered at 0.5).

Materials

The stimuli were morphs of bald male faces selected from Kayser (1997) using the blending technique outlined in Steyvers (1999). A stimulus space was constructed that varied along two arbitrary dimensions, each one formed by morphing between two anchor faces to create 10 faces per dimension that formed a continuum from one anchor face to the other (see Dimensions 1 and 2 in Figure 1). The two specific dimensions used in this study were selected because they were roughly equally salient and roughly orthogonal when subjected to a MDS analysis in preliminary work (Gureckis & Goldstone, 2008). A 10 by 10 matrix of stimuli faces were created by combining each face along dimension 1 with each face along dimension 2 to create a blended face that is the average of the two faces. Not all 100 faces in the 10 by 10 matrix were presented during categorization trials. In particular, a subset of faces was never presented (the light grey faces in Figure 1), creating two "clusters" of faces within each category.

Procedure

Categorization Task On each categorization trial, a single face was presented for 500 ms in the center of the display for study followed by a blank screen for 300 ms. Instructions were then presented directing participants to indicate if the correct category label for the item was 'P' or 'Q.' After a participant responded, the stimulus was again presented for 2000 ms along with feedback indicating whether the response was correct and the correct category of the stimulus.

Discrimination Task On each trial, a target stimulus was presented for 500 ms in the center of the display for study followed by a blank screen for 300 ms. For discrimination trials, immediately after the blank screen two stimuli were simultaneously presented: one stimulus that exactly matched the target stimulus and a foil stimulus. Participants were instructed to indicate by pressing one of two keys which stimulus matched the target. No feedback was provided after discrimination trials.

Sixteen stimuli were used as targets and foils in the discrimination task: the four corners of each of the four clusters shown in Figure 1 (e.g. stimuli A7, A10, D7 and D10 of the lower left-hand cluster). Each foil stimulus was two values away from the target stimulus on one of the two dimensions or two values away from the target stimulus on both dimensions (e.g. for stimulus A1 the set of foils was D1, A4, and D4; for stimulus D4 the set of foils was: A4 and G4 along Dimension 1, D1 and D7 along Dimension 2, as well as A1, G1, G7, and A7 along both dimensions).

Interference Tasks The verbal and spatial interference tasks involved participants memorizing a verbal string or a spatial pattern and recalling that information after a mini-block of categorization and discrimination trials. Verbal interference mini-blocks were preceded by the presentation of a string of 6 digits for 8 s followed by an interval of 3 s. Participants were instructed that they should memorize this string and would be tested on it later. At the end of the mini-block, memory for the studied string was probed by presenting the original string along with a foil stimulus (which had two randomly selected digits swapped). Participants simply indicated which string they recognized as the studied item by pressing one of two keys.

Spatial interference mini-blocks were preceded by the presentation of a 6 by 6 grid composed of half white squares and half black squares for 8 s followed by an interval of 3 s before the mini-block began. Participants were instructed to memorize this pattern and that they would be tested on it. At the end of the mini-block, recall of the pattern was tested by presenting the original pattern and a foil pattern that had the black-white state of one randomly selected square different than the original pattern.

A pilot study was done to control for the relative difficulty of the spatial and verbal interference tasks. The number of squares in the spatial interference task (36) and the length of the number of digits in the verbal interference task (8) were selected such that participants performed equally well at the discrimination task for the two interference tasks (0.72 vs. 0.73, spatial vs. verbal interference, $t(21) < 1$, $p = 0.58$). Participants in the pilot study were not exposed to any categorization trials.

The complexity of the verbal and spatial tasks differed from those used by Winawer et al. (2007). They used a verbal string of length 8 and a 4 by 4 grid for their spatial pattern. Using a pretest they found no significant differences in accuracy on the interference judgment for those two tasks. In our pilot study, we found a significant difference on discrimination performance (with no categorization training) between their two conditions (0.76 vs. 0.71, spatial vs. verbal, $t(21) = 2.26$, $p = 0.03$).

Phase 1: Mixed Categorization and Discrimination Phase one consisted of two blocks of 120 categorization learning and discrimination trials presented without interference tasks. This allowed participants to begin learning the correct categories before introducing interference tasks. Trials were randomly mixed such that for each mini-block of 15 consecutive trials, 8 trials were categorization and 7 were discrimination, randomly ordered and intermixed. Note that participants did not know the type of judgment they would have to make (categorization or discrimination) until after the stimulus disappeared. This manipulation increases the relevance of processing category-level information during discrimination. The first block of phase one discrimination trials was used as a baseline measurement of performance before learning.

Phase 2: Interference Tasks with Mixed Categorization and Discrimination Phase two consisted of 21 mini-blocks composed of eight categorization and eight discrimination trials presented in a random order. Of the 21 blocks, seven had a verbal interference task, seven had a spatial interference task, and seven had no interference task. The order of mini-blocks was randomized across participants.

Results

For all analyses presented below, responses faster than 150 ms (less than 2% of all responses) were excluded from analysis. Including these fast trials in the analyses does not change the significance of the results.

Interference Task Performance In phase two participants demonstrated above chance performance on the spatial interference task ($M = 0.89$, $SD = 0.08$, $t(110) = 31.5$, $p < 0.001$) and the verbal interference task ($M = 0.95$, $SD = 0.13$, $t(110) = 59.4$, $p < 0.001$). A paired-sample t-test found a significant difference in performance between accuracy on the two test types ($t(110) = 4.51$, $p < 0.001$). Participants were more accurate on the verbal interference task.

Categorization Performance In phase two participants demonstrated above chance categorization performance in the no interference condition ($M = 0.83$, $SD = 0.12$, $t(110) = 28.3$, $p < 0.001$), the verbal interference condition ($M=0.82$, $SD = 0.12$, $t(110) = 28.9$, $p < 0.001$), and the spatial interference condition ($M = 0.82$, $SD = 0.12$, $t(110) = 28.2$, $p < 0.001$). There was not a significant difference in categorization performance across interference conditions (F(2,220) = 0.1, Mse = 0.0003, p = 0.9).

Discrimination Performance Discrimination trials were classified based on the relationship of the target and foil face stimuli and the category boundary. Trials were classified as *within-cluster* if both faces were contained in the same group, and therefore within the same category as well. If the faces were in different clusters but still in the same category, those trials were classified as *within-category*. All remaining trials contained faces that were in different categories and were classified as *between-category*.

Discrimination performance during phase two, containing interference tasks (blocks 3 and 4), was assessed as a change in performance relative to a baseline performance on discrimination trials. The average for each participant of all discrimination trials in the first block (all possible 56 discrimination pairs) of phase one was used as this baseline measure. Removing baseline performance minimizes the variance due to any initial differences in discrimination ability across individuals. In all the following analyses this change in discrimination performance was used as the dependent measure.

Discrimination Performance across all Interference Tasks A repeated-measures ANOVA with discrimination type (3 levels) as a within-subject variable found a significant main effect of discrimination type on change in discrimination performance (F(2, 220) = 14.83, Mse = 0.06, p < 0.001). Planned comparisons between discrimination types found significant differences between *between-category* and *within-category* conditions (t(110) = 2.63, p = 0.010), between *within-category* and *within-cluster* conditions (t(110) = 2.61, p = 0.010), and between *between-category* and *within-cluster* conditions (t(110) = 5.98, p < 0.001).

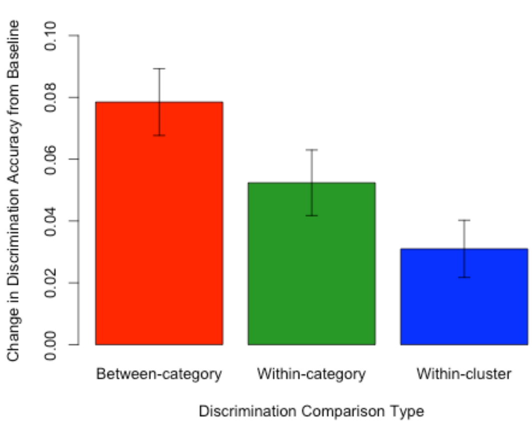

Figure 2: The change in discrimination performance relative to baseline averaged across interference condition. Participants show an increase in discrimination performance for all discrimination types relative to baseline (block 1), but a larger increase for judgments that cross category or cluster boundaries than are within-cluster. All error bars are standard errors.

Figure 2 shows these results support the predicted pattern of results and replicate the general pattern of results reported in Gureckis and Goldstone (2008). The learned CP effect was found: perceptual discriminations that span category boundaries showing the largest increase. Participants also learned the internal structure of categories, reflected in the significant difference between *within-category* and *within-cluster* perceptual discriminations, where discriminations that span within-category clusters had a larger increase. The main difference from Gureckis and Goldstone (2008) was that an increase in perceptual discrimination was found for all discrimination conditions (Gureckis and Goldstone (2008) found a non-significant decrease in the *within-cluster* condition).

Discrimination Performance within Interference Tasks A repeated-measures ANOVA with interference condition (3 levels: none, verbal, and spatial) and discrimination task (3 levels: as above) was performed with change in discrimination performance as the dependent measure. A main effect of discrimination type was found (F(2,220) = 14.78, Mse = 0.19, p < 0.001). Surprisingly, there was no main effect of interference task (F(2,220) = 0.29, Mse = 0.003, p = 0.75), nor a significant interaction between discrimination type and interference condition (F(4,440) = 0.77, Mse = 0.008, p = 0.55). Figure 3 shows this result.

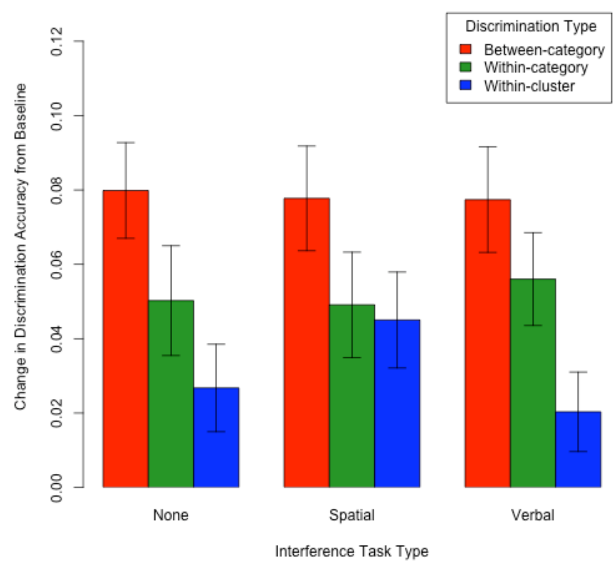

Figure 3: The effect of discrimination type and interference condition on change in discrimination performance relative to baseline (block 1). Participants show a consistent pattern in which *Between-category* improvement is greater than *Within-category* improvement, which is greater than *Within-cluster* improvement. There is no effect of interference condition or an interaction with discrimination type. All error bars are standard errors.

Within each interference condition the same pattern of results hold as across all conditions. *Between-category* discriminations increase more relative to baseline than *within-category*, which increases more than *within-cluster*. The difference in improvement between *between-category* and *within-category* is marginally significant for the no interference ($t(110) = 1.80$, $p = 0.075$) and the spatial interference conditions ($t(110) = 1.79$, $p = 0.077$), and not significant for the verbal interference condition ($t(110) = 1.34$, $p = 0.18$). The difference between *within-category* and *within-cluster* improvement is significant in the verbal interference condition ($t(110) = 2.50$, $p = 0.01$), marginally significant for the no interference condition ($t(110) = 1.81$, $p = 0.073$), and not significant in the spatial interference condition ($t(110) < 1$, $p = 0.75$). The difference in improvement between *between-category* and *within-cluster* is significant for all interference conditions (none ($t(110) = 3.75$, $p < 0.001$), spatial ($t(110) = 4.47$, $p < 0.001$), and verbal ($t(110) = 4.47$, $p < 0.001$).

Discrimination Performance grouped by Categorization Performance Following Gureckis and Goldstone (2008), an analysis was performed on the effect of discrimination task on discrimination performance within mini-blocks as a function of the accuracy of categorization trials within that mini-block. For each participant, mini-blocks selected from trials in phase two were grouped based on categorization accuracy within the mini-block into high categorization (75-100%, 322 mini-blocks among 107 subjects), medium categorization (50-75%, 312 mini-blocks among 79 subjects), and low categorization (0-50%, 124 mini-blocks among 22 subjects). Figure 4 shows these results.

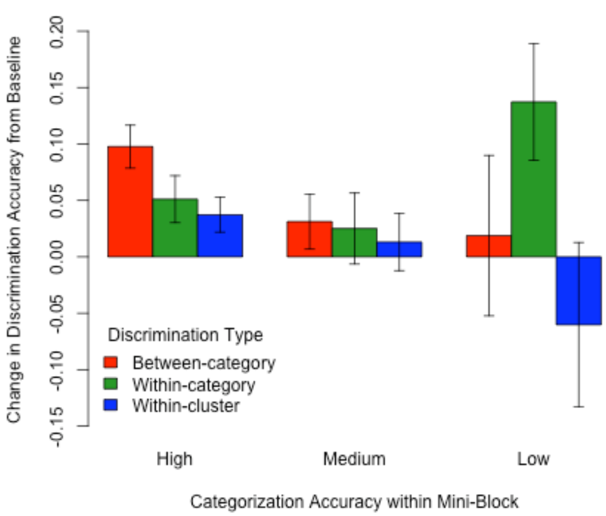

Figure 4: All bars are standard error bars but not all conditions had the same number of participants. Participants who did not have any low categorization accuracy mini-blocks did not contribute to the number of participants in the low categorization conditions. The small number of observations in the within-category low accuracy condition may have contributed to what appears to be a spuriously high increase in that condition.

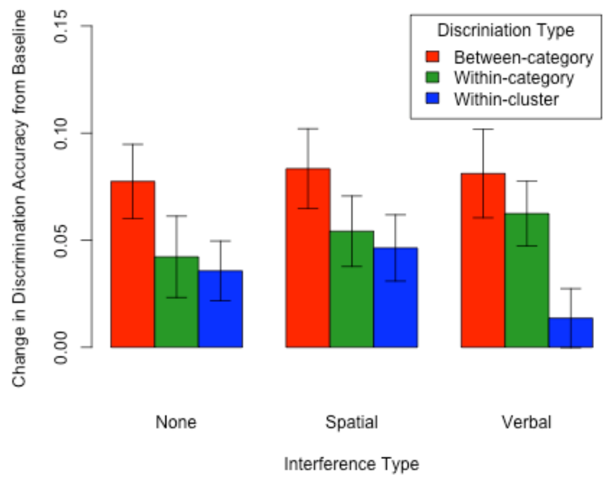

Figure 5: The effects of discrimination type and interference condition on change in discrimination performance relative to baseline for mini-blocks in which categorization accuracy was above 75%. Participants show a consistent pattern in which *Between Category* improvement is greater than *Within Category (Between Cluster)* improvement, which is greater than *Within Cluster* improvement. There is no effect of interference condition or an interaction with discrimination type. All error bars are standard errors.

The pattern of results in the high categorization accuracy set follows those of Gureckis and Goldstone (2008). The pattern among low categorization performance mini-blocks may be an artifact of having few participants at that level.

Looking specifically in the high categorization performance group (figure 5) where CP effects were predicted to be strongest and thus easiest to see an influence of interference condition, a repeated-measures ANOVA was performed with interference condition (3 levels) and discrimination type (3 levels) as within-subject factors. There was a significant main effect of discrimination type ($F(2, 214) = 8.56$, $Mse = 0.19$, $p < 0.001$) but not of interference condition ($F(2,214) = 0.4$, $Mse = 0.009$, $p = 0.66$) and no significant interaction between the two factors ($F(4,424) = 0.68$, $Mse = 0.02$, $p = 0.60$).

The high-categorization mini-block results echo our previous results (Figure 3) showing a strong effect of discrimination type but no influence or interaction with interference condition.

Discussion

Consistent with Gureckis and Goldstone (2008), we found strong evidence for learned categorical perception across the category boundary as well as learned sensitivity to the structure of information within the categories. This learning effect was strongest when averaged across all interference conditions, but the same pattern was exhibited in each interference condition: *between-category* discriminations improved the most, followed by *within-category* discriminations, and *within-cluster* discriminations improved the least. This pattern was found within each interference condition with varying degrees of reliability. As predicted, it was also consistently found in mini-blocks that had high accuracy on categorization trials, more so than in blocks with low categorization accuracy.

Surprisingly, we did not find any indication that the interference tasks modulated the effects of learning either categorical perception or within-category structure. Additionally, no main effect of interference condition was found across all discrimination conditions. This was true across all discrimination trials as well as those in mini-blocks with high categorization accuracy. The lack of interaction between interference condition and discrimination type is less startling than the lack of main effect of interference condition on overall discrimination performance because the difficulty of the spatial and verbal interference tasks was selected based on pilot data to have a relatively equal effect on perceptual discrimination tasks. The lack of main effect of interference condition is consistent with the results of Russian speakers in the Winawer et al. (2007) study (who only found an interaction between interference condition and the CP effect), though their interference tasks were pretested to equate for accuracy on the interference task itself. Winawer et al. also did not find an interaction between categorical perception and interference condition among the English speakers who did not show a main effect of categorical perception. This is not consistent with learners in our task who did show categorical perception, as well as sensitivity to inter-category structure, but did not show an interaction with interference condition.

This current work suggests that firmly entrenched verbal labels, such as color names (Winawer et al., 2007) or basic shapes (Lupyan, 2009), may be necessary to see verbal interference effects in perceptual discrimination. The incidentally learned information about the structure of categories that underlies the results found in Gureckis and Goldstone (2008) and replicated here may not have verbal labels attached that are influenced by an interference task. Instead, the preservation of this pattern across interference conditions is consistent with the non-verbally mediated account of CP that directs the focus of learning toward learning to weight perceptual dimensions rather than rely on verbal labels for categories. Clearly, the lack of effect of interference task does not justify strong claims about the nature of learned CP effects. However it does suggest that for non-automated categories verbal labels might not tell the whole story about what learning drives CP. Further work is needed to bridge the gab between our understanding of entrenched categories that do show verbal interference effects and newly-learned categories that might not, and how representations may change to incorporate more information about verbal labels.

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