

Support for lateralization of the Whorf effect beyond the realm of color discrimination

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Abstract

Recent work has shown that Whorf effects of language on color discrimination are stronger in the right visual field than in the left. Here we show that this phenomenon is not limited to color: The perception of animal figures (cats and dogs) was more strongly affected by linguistic categories for stimuli presented to the right visual field than those presented to the left. Moreover, the magnitude of the visual field asymmetry was reduced when demands on verbal working memory were increased by a secondary task. This reduction did not occur when the secondary task imposed demands on spatial working memory. Taken together, these results demonstrate that the lateralized Whorf effect may be quite general, reflecting an interaction of linguistic and perceptual codes primarily in the left hemisphere.

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1. Introduction

Research addressing the existence of a Whorf effect—a shaping of cognition and perception by one's native language (Whorf, 1956)—has been hotly debated for many years, and the dispute continues (e.g., Casasanto, 2005; Gordon, 2004, 2005). Much of the work surrounding the issue has focused on perceptual discrimination of colors in speakers of different languages. For example, in an early study, Kay and Kempton (1984) found that English speakers perceive colors that cross the lexical boundary between “green” and “blue” to be less similar than do Tarahumara speakers of Mexico, who use the same word to identify both of these colors, and thus lack a lexical boundary at

this position in color space. In the same set of experiments, they also determined that when the English-speaking participants' verbal processing was interrupted, this disparity in perception between the two groups disappeared, suggesting that the English-speakers' relative exaggeration of perceptual distance at the inter-word boundary was due to the on-line use of lexical codes. However, while some researchers have found effects of language on elements of cognition and perception (Kay & Kempton, 1984; Roberston & Davidoff, 2000; Winawer et al., 2003) others have not (Franklin, Clifford, Williamson, & Davies, 2005; Heider, 1972; Heider & Olivier, 1972).

For right-handed individuals language function is more strongly associated with the left hemisphere (LH) compared to the right hemisphere (RH) (Wada, Clarke, & Hamm, 1975). Given this aspect of hemispheric specialization, and the crossing of projections in the visual system, the Whorf effect of language on perception might be more evident for stimuli presented in the right visual field (RVF)

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than the left visual field (LVF). Previous lateralization research is compatible with this hypothesis (e.g., Davidoff, 1976; Nishimura, 2006; Simon, Paullin, Overmyer, & Berbaum, 1985).

We (Gilbert, Regier, Kay, & Ivry, 2006) tested this hypothesis directly using a lateralized visual search task. Participants viewed a ring of colored squares, one of which (the target) was presented in a different hue than the other 11 squares. They performed a speeded visual discrimination task, indicating whether the target was present in the left or right visual field. Reaction times (RTs) were faster when the target belonged to a different lexical category than the distractors (e.g., blue among greens) compared to when the target and distractors were from the same lexical category (e.g., two different hues of green). However, this effect was only observed when the target appeared in the right visual field; RTs to targets in the left visual field did not vary as a function of the categorical relationship between the target and distractors.

A lateralized Whorf effect has also been observed in other experiments using different color discrimination tasks (Drivonikou et al., 2007). This corroborating evidence comes from a post hoc reanalysis of the data obtained in a color discrimination task (Daoutis, Pilling, & Davies, 2006) as well as two additional visual search experiments in which participants had to find a target color against a uniform background. Consistent with the findings of Gilbert et al. (2006), these experiments found that identification of those targets was faster in the RVF when targets were from a different lexical category than distractors. Drivonikou et al. (2007) also observed a reliable, albeit weaker, effect in the LVF.

The lateralized Whorf experiments conducted to date have focused exclusively on color perception. If the asymmetric effect reflects a general influence of language on performance, it should not be limited to color discrimination. In the current study, we employ the visual search task of Gilbert et al. (2006), but replace the colors with pictures of cats or dogs. For a between-category trial, the target is a cat presented among dog distractors or vice-versa. For a within-category trial, a cat target is presented among other cats or a dog is presented among other dogs.

We tested three predictions based on the hypothesis that language disproportionately influences discrimination in the RVF compared with the LVF. First, discrimination between items from different lexical categories (i.e., that have different names, in this case, “dog” or “cat”) should be faster when stimuli are displayed in the RVF than when they are displayed in the LVF because the lexical distinction should enhance the perceptual difference. Second, discrimination between items from the same lexical category should be slower in the RVF than in the LVF, because the assignment of the same name should diminish the perceptual difference. Third, the visual field asymmetry should be attenuated or eliminated under conditions of concurrent verbal interference but unaffected under conditions of comparable non-verbal interference.



Fig. 1. Cat and dog stimuli used in experimentation.

2. Experiment 1

In order to test the predictions outlined above, we used an adapted version of the lateralized visual search task employed by Gilbert et al. (2006). The stimuli were black silhouettes of four shapes—two dogs and two cats. Gilbert et al. (2006) attempted to equate the psychological distance between neighboring color stimuli. This was not possible here nor did we see it as essential given that we are predicting a visual field \times category relationship interaction. We did not control for all perceptual features but constructed stimuli of similar overall shape and size, and same number of pixels (Fig. 1).

2.1. Methods

Twelve participants were recruited from the University of California, Berkeley community. The participants (mean age 18 years) were right-handed, native English speakers with normal or corrected-to-normal vision. To verify that the stimuli could be readily identified and correctly labeled under limited exposure conditions, a naming task was conducted. Individual stimuli were presented in random order for 200 ms in the center of the screen and the participants named whether the picture was of a dog or cat. Each of the four stimuli was presented 10 times in total. All of the participants correctly classified each stimulus without any errors.¹

In the visual search task, participants sat in a dimly illuminated room with the center of the computer screen at eye level. Each trial began with the onset of a central fixation marker. After 1000 ms, a stimulus display appeared, consisting of a ring of 12 animals surrounding the fixation marker. The diameter of the ring was approximately 8.5°. Eleven of the animals were the same (the distractors) and the twelfth animal was different (the target). The target was from either the same category (e.g., a cat among cat distractors) or from a different lexical category (e.g., a cat among dog distractors). All of the animals faced the vertical meridian, ensuring that each feature (e.g., head) was equidistant from the center for corresponding positions in the left and right visual field (Fig. 2).

¹ We conducted a set of pilot experiments to assess whether the naming task would influence performance on the visual search task, perhaps by priming lexical access. In the pilot work, the naming task was conducted either before or after the search task. Order did not affect search performance.

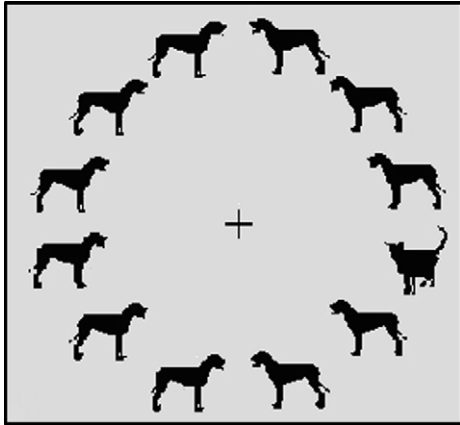


Fig. 2. Sample display for the visual search task with a between-categories stimulus pair. Participants were required to press one of two response keys, indicating the side containing the target.

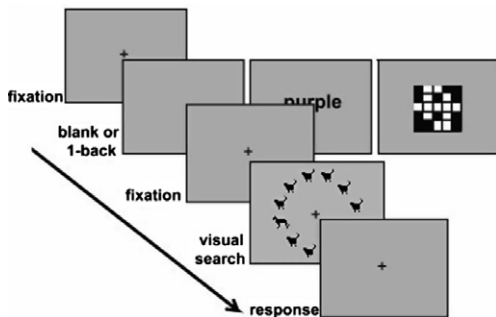


Fig. 3. Trial events. Within a block of trials, the visual search task was interleaved with blank displays, displays containing a color word, or displays containing a spatial grid.

Participants were asked to identify the side of the screen containing the target (the “odd man out”) as quickly as possible. Responses were made by pressing one of two horizontally aligned keys on the keyboard, using either the left (“Q” key) or right (“P” key) index finger. The visual search display remained visible for only 200 ms, an interval selected to discourage eye movements. We did not mask the displays; rather, the fixation cross remained visible until the participant responded. Following the response, the screen went blank for 200 ms prior to the reappearance of the fixation cross to mark the beginning of the next trial.

There were 6 target–distractor pairs, formed by using all pairwise combinations of the four stimuli (Cat₁Cat₂, Dog₁–Dog₂ (the two within-category pairs), Cat₁Dog₁, Cat₁–Dog₂, Cat₂Dog₁, Cat₂Dog₂ (the four between-categories pairs)). By having each member of a pair serve as target and distractor in different trials, there were 12 possible target–distractor configurations. Because the target could occupy any of the 12 positions, there were 144 possible stimulus configurations. Each participant completed six 144-trial blocks, with each stimulus configuration used once per block. The order of trials within a 144-trial block was randomized.

Trials in which the participant pressed the wrong key or any non-designated key, or in which the RT fell outside of two standard deviations from the participant’s mean were not included in the analysis of the data. About 8% of all trials were excluded by these criteria, 70% of which were because of erroneous responses. There was an approximately equal distribution of excluded trials between the two visual fields, and error rates were slightly higher for within-category (58%) than between-categories trials (42%). There were no significant differences in participants’ reaction times based on which of the two stimuli in each pair served as target.

2.2. Results

The RT data were analyzed using a 2 (visual field: left vs. right) × 2 (pair type) ANOVA. There was a reliable main effect of pair type, with RTs to between-categories pairs faster than to within-category pairs [$F(1, 11) = 15.87, P < .001$]. While the effect of visual field was not significant [$F(1, 11) = 2.13, P = .17$], the interaction of visual field and pair type was [$F(1, 11) = 12.81, P < .001$], with the RVF registering more rapid discrimination of between-category targets than the LVF as predicted. Data were also examined by upper and lower visual fields. Neither an effect of VF (upper vs. lower) [$F(1, 11) = 1.94, P = .19$] nor the interaction between this factor and pair type [$F(1, 11) = 2.51, P = .14$] were reliable.

For LVF targets, participants’ responses to the between-categories pairs were 47 ms faster than for the within-category pairs ($t(11) = 2.49, P < .02$). This between-category advantage was considerably larger for RVF targets: here between-categories pairs were 113 ms faster than within-category pairs ($t(11) = 3.78, P < .01$). In a comparison of the pair types, mean RT on within-category trials was 35 ms faster when the target appeared in the LVF than in the RVF ($t(11) = 2.08, P < .05$) while mean RT on between-categories trials was 31 ms faster when the target appeared in the RVF ($t(11) = 1.82, P < .05$) (Fig. 4).

The results of Experiment 1 are consistent with the hypothesis that linguistic categories influence perceptual dis-

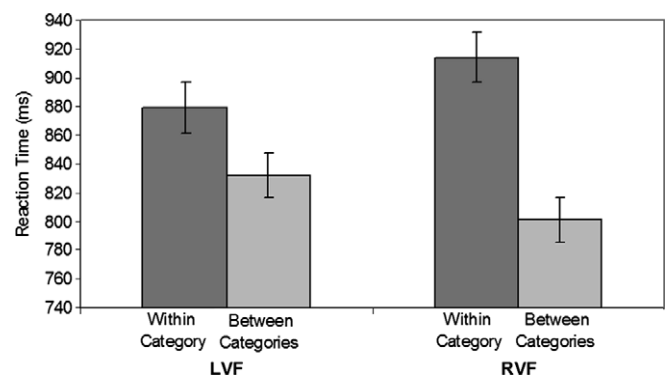


Fig. 4. Visual search task results from 12 participants. Error bars show 95% confidence limits.

crimination differently in the two visual fields. The stimulus names modulated performance, enhancing between-categories distinctions and reducing within-category distinctions. Most important, these effects were more pronounced for RVF targets compared to LVF targets. Thus, both of the first two hypotheses were supported: between-categories discrimination was faster in the RVF and within-category discrimination was slower in the RVF, presumably due to the stronger activation of lexical codes associated with stimuli that are presented in the RVF. However, the results differed slightly from previous testing with color stimuli. Whereas Gilbert et al. (2006) documented a strong Whorf effect in the RVF but none in the LVF, here we observed effects in both visual fields, albeit with a stronger effect in the RVF. This finding is consistent with more recent analyses by Drivonikou et al. (2007).

3. Experiment 2

One way to verify that any lateralized effect observed in Experiment 1 can be attributed specifically to language functions is to conduct the visual search task with a secondary task designed to tax verbal working memory. To this end we applied the same strategy employed by Gilbert et al. 2006, Experiment 2. Participants performed the visual search task concurrently with a secondary task of either a verbal or a nonverbal nature (Gilbert et al., 2006; Robertson & Davidoff, 2000; Winawer et al., 2003). The goal of Experiment 2 was to determine what, if any, effects these two types of secondary tasks might have on participant responses in the visual search task. We predicted that the verbal secondary task would attenuate both the RVF advantage for detecting between-category targets, and the RVF disadvantage for detecting within-category targets.

3.1. Methods

Eleven right-handed, native English speakers with normal or corrected-to-normal vision were recruited from the UC Berkeley community (mean age 19 years).

Testing began with the naming task described in Experiment 1 with the exception that the experimenter did not prompt the labels “cat” and “dog”. This modification allowed us to verify that the participants spontaneously used basic category terms (i.e. “dog” instead of something like “golden retriever”).

Following the naming task, there were three primary experimental conditions in the visual search task: no-interference, verbal interference, and nonverbal interference. The visual search and interference displays were interleaved (Fig. 3). For the verbal interference task, the displays consisted of a single color word drawn from the set: “beige,” “black,” “brown,” “gray,” “orange,” “pink,” “purple,” “red,” “violet,” “white,” and “yellow.” For the nonverbal interference task, the displays consisted of a 5 cm × 5 cm grid in which 12 of the 25 squares were black and 13 were white. A set of 15 grid displays was created. On no-interfer-

ence blocks, a blank screen was presented in lieu of an interference display.

At the start of each trial, a fixation marker was presented for 1250 ms. It was then replaced by a blank screen (no-interference), a color name (verbal interference), or one of the grids (nonverbal interference) for 1250 ms. The fixation screen then reappeared for another 1250 ms, followed by the visual search display for 200 ms. As in Experiment 1, the instructions emphasized that participants should respond as quickly as possible to the visual search displays by using their left or right index fingers to indicate the side of the target.

During interference blocks, they were also required to press the space bar with both thumbs whenever they detected that the secondary task stimulus (the word or grid) was the same as that shown in the previous display (1-back match). No response was required when the secondary task stimulus changed. The percentage of 1-back matches was set to 10% of trials. Pilot testing had been conducted to identify verbal and nonverbal interference tasks that were demanding and of equal difficulty. In terms of performance during the actual experiment, participants correctly detected the secondary task targets on 92% and 89% of the trials in the verbal and spatial conditions, respectively.

We halved the number of target–distractor pairs by randomly selecting one member of each pair to serve as the target on all trials with that pair. For example, for the pair Cat₁ and Cat₂, one member always served as the target and the other always as the distractor. This reduced the total number of stimulus displays to 72 (six pairs, with the target appearing in each of the 12 possible locations). This modification allowed us to accommodate the additional interference conditions in Experiment 2, while keeping the total experimental session to approximately 1 h. Each participant completed four 72-trial blocks for each of the three conditions: visual search task with no-interference, verbal interference, and nonverbal interference. The block types were interleaved and the order of the three tasks was counterbalanced across subjects. A 15-trial practice block preceded the first test block for each condition.

The analysis of the visual search data did not include trials following an overt response on the secondary task because RTs on the subsequent primary task may be slower due to a post-response refractory period (e.g., DeJong, 1993; Pashler, 1984; Van Selst & Jolicoeur, 1997; Welford, 1952). In addition, trials were eliminated based on the accuracy and speed criteria established for Experiment 1. About 22% of all trials were excluded by these criteria: 11% because of preceding responses on the interference tasks (including both correct responses and a few false alarms) and 8% because of erroneous responses on the visual search task. The percentage of visual search errors was similar in the verbal (5%) and nonverbal (3%) conditions. While there was an approximately equal distribution of excluded trials between the two visual fields, error rates were 12% higher for within-category than between-categories trials.

3.2. Results

The results for the no-interference and nonverbal interference conditions replicated those observed in Experiment 1. In contrast, the verbal interference task disrupted the RVF advantage for between-category pairs. A three-way ANOVA [(VF: RVF vs. LVF) \times (pair type: within-category vs. between-categories) \times (interference type: verbal vs. nonverbal)], revealed a significant three-way interaction between VF, pair type, and interference condition. [$F_{(2,20)} = 8.17, P < .005$] (Fig. 5).

3.2.1. No-interference

For the no-interference condition, there was a significant effect of pair type [$F_{(1,10)} = 10.78, P < .001$], with RTs faster for between-categories pairs in both visual fields. While the effect of VF alone was not significant, [$F_{(1,10)} = 1.79, P = .21$], the interaction between pair type and VF was [$F_{(1,10)} = 11.12, p < .01$] (Fig. 5a).

For LVF targets, participants' responses to the between-categories pairs were 34 ms faster than to the within-category pairs ($t(10) = 1.89, P < .05$); for RVF targets, responses to the between-categories pairs were 103 ms faster than to the within-category pairs ($t(10) = 3.04, P < .005$). Examining each of the pair types individually, mean RT was 32 ms faster when within-category targets appeared in the LVF than in the RVF ($t(10) = 1.88, P < .05$), and, conversely, 37 ms faster when between-category targets appeared in the RVF than in the LVF ($t(10) = 1.92, P < .05$) (Fig. 5a).

3.2.2. Nonverbal interference

Results of the nonverbal interference condition mirrored those of Experiment 1 and the no-interference condition of this experiment (with slightly increased response times): There was a significant main effect of pair type

[$F_{(1,10)} = 9.80, P < .01$], with RTs faster for between-categories pairs in both visual fields; While the effect of VF was not significant [$F_{(1,10)} = 2.94, p = .12$] the interaction between pair type and VF was [$F_{(1,10)} = 10.10, P < .01$]. When these two factors were analyzed separately, the results were again consistent with that observed in the no interference condition. A between-category advantage was found in both visual fields, although this effect was larger in the RVF (80 ms, $t(10) = 3.14, P < .005$) than in the LVF (40 ms, ($t(10) = 2.99, P < .01$)). When analyzed by pair type, a marginally significant advantage was observed on within-category trials when the target appeared in the LVF, compared with the RVF (13 ms, $t(10) = 1.59, P = .07$). For between-categories pairs, mean RTs were 27 ms faster when the target appeared in the RVF, compared with the LVF ($t(10) = 1.98, P < .05$) (Fig. 5b).

3.2.3. Verbal interference

Similar to the other two conditions, the main effect of pair type remained significant in the verbal interference condition [$F_{(1,10)} = 4.89, P < .05$], with RTs for between-category pairs faster than those for within-category pairs. The effect of VF was not reliable [$F_{(1,10)} = 3.12, p = .11$]. Most striking, however, is that, while there was a significant interaction between pair type and VF [$F_{(1,10)} = 8.24, P < .05$], the form of this interaction is opposite that observed in the no-interference and nonverbal interference conditions. The between-category advantage was now significantly greater when the target appeared in the LVF (Fig. 5c).

In the LVF RTs to between-categories pairs were 36 ms faster than those to within-category pairs ($t(10) = 2.21, P < .05$). For RVF targets the 22 ms difference between RTs for the two pair types was only marginally reliable ($t(10) = 1.58, P = .07$). When analyzed by

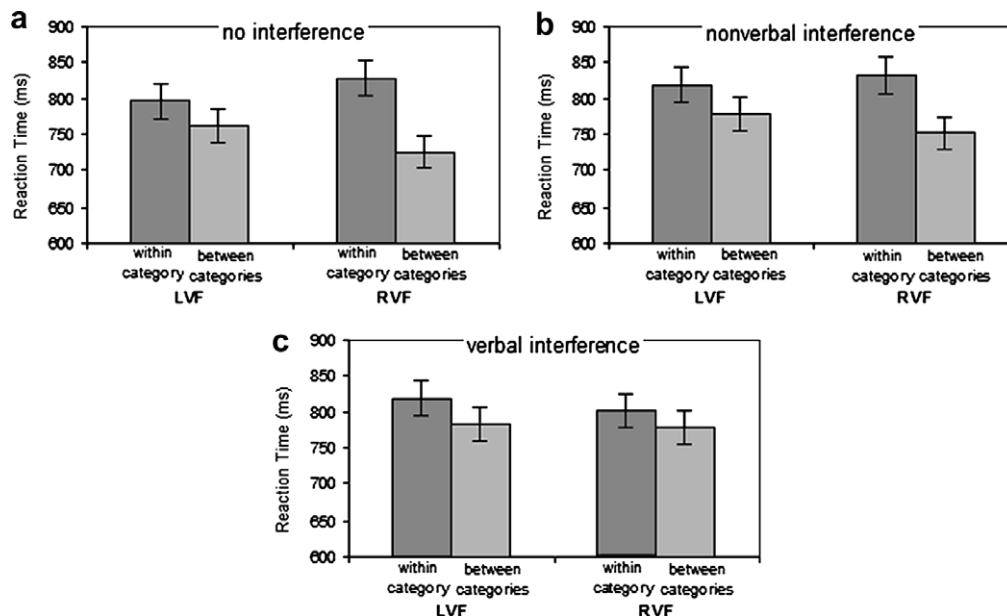


Fig. 5. Data for conditions without interference and with verbal and nonverbal tasks ($n = 11$). Error bars show 95% confidence limits.

pair type, RTs were marginally faster (18 ms) for within-category pairs when the target appeared in the RVF compared with the LVF ($t(10) = 1.61, P = .07$). This result is opposite to that found in the no-interference and nonverbal interference conditions, suggesting that when the LH is engaged by a verbal secondary task, the selective disadvantage for within-category pairs is reduced. Finally, RTs for between-categories pairs were not significantly different in the two visual fields ($t(10) = 0.56, P = .29$), a result that contrasts with that found in the other two conditions in which a RVF advantage had been observed.

The results of Experiment 2 are consistent with the hypothesis that language modulates perceptual discrimination by means of lexical categories more in the RVF than in the LVF. This pattern is disrupted by verbal, but not by nonverbal, interference, supporting the third prediction outlined in the introduction.

4. Experiment 3

Callosotomy patients, who have had the main connection between the two hemispheres of their brain severed, provide a more direct means of biasing the processing of information from each VF to the contralateral hemisphere. Because of the reduced communication between the two hemispheres, we might expect asymmetries observed in normal participants to be amplified in these patients. There is a long history of testing these patients in lateralization research (e.g., Corballis, Funnell, & Gazzaniga, 2002; Frey, Funnell, Gerry, & Gazzaniga, 2005).

4.1. Methods

We tested callosotomy patient VP on the same visual search task described in Experiment 1. In 1979 VP underwent a two-stage callosotomy for the control of intractable epilepsy at the age of 27 years. Her post-surgery intelligence fell within a normal range (Gazzaniga, Nass, Reeves, & Roberts, 1984a, 1984b). Sidtis, Volpe, Wilson, Rayport, and Gazzaniga (1981) and Gazzaniga et al. (1984a, 1984b) provide extensive background on VP's medical history and cognitive abilities.

Although it is reported last here, we actually conducted the testing with VP before we conducted Experiments 1 and 2. We used slightly different stimuli in this earlier testing. Instead of being solid black, the two dog and two cat figures were grayscale, matched for luminance and size. These stimuli were selected from a pool of on-line images based on level of detail and animal stance.

Testing was conducted at VP's home with a laptop computer. Following a short practice round of 20 trials, VP performed four blocks of the visual search task with no secondary tasks. Each block consisted of 72 trials, as described in Experiment 2. Approximately 4% of VP's trials were excluded by using the criteria described in Experiment 1. Of these excluded trials, 68% involved erroneous responses and the remainder had RTs beyond 2 *SD* from

the mean. The erroneous responses happened more frequently for targets in the LVF (72% of erroneous responses).

4.2. Results

For VP, the influence of category membership was limited to the right visual field. Whereas RVF targets RTs were 63 ms faster for between-category pairs ($t(1) = 10.8, P < .03$), there was no significant difference in RT to the two different types of targets when they appeared in the LVF ($t(1) = 2.33, P = .13$) (Fig. 6). A 2 (VF) \times 2 (pair type) ANOVA with block as a repeated factor found a significant main effect of pair type [$F(1, 3) = 11.04, P < .05$] but not of VF [$F(1, 3) = 1.78, P = .27$]. The interaction was significant [$F(1, 3) = 16.61, P < .03$]. For within-category pairs, RTs were 34 ms faster when the target appeared in the LVF compared with the RVF ($t(1) = 6.71, P < .05$), while for between-categories pairs, the opposite trend approached significance, with RTs 23 ms faster when the target appeared in the RVF compared with the LVF ($t(1) = 5.99, P = .052$).

The results of Experiment 3 resemble those of Experiment 1 and the no-interference and nonverbal interference conditions of Experiment 2. Compared to the neurologically intact participants, the callosotomy patient demonstrates a more stark contrast between the two visual fields. Modulation of discrimination by lexical categories was only observed in the RVF. The lack of a pair type effect in the LVF suggests that the weak LVF effect observed in normal participants may be due to interhemispheric transfer, rather than some "native" RH processes.

5. General discussion

The results of these experiments support previous findings of a lateralized Whorf effect and also serve to generalize the lateralized Whorf effect to non-color stimuli. Here this effect manifests itself in two ways: (1) enhanced performance when the perceptual discrimination is between items

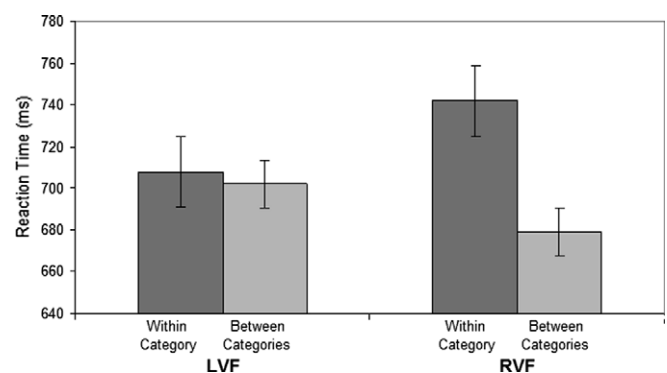


Fig. 6. Visual search task results from callosotomy patient testing. Error bars show 95% confidence limits.

from different lexical categories in the RVF as compared to the LVF; (2) impaired performance when the perceptual discrimination involves items from the same lexical category in the RVF as compared to the LVF.

An important question that is raised—but not answered—by our findings is by what mechanism language influences perceptual discrimination. Our within-subject design argues against the role of strategic processes. It seems unlikely that the participants would adopt one strategy when the target was in the right visual field and a different one when the target was in the left visual field. Regardless, the disruption of Whorf effects by verbal interference strongly suggests that language affects discrimination on-line through the activation of lexical codes, rather than through a long-term, enduring warping of perceptual space. What is not clear, however, is whether this on-line influence affects perception itself, or a post-perceptual decision process.

Consider first a perceptual account. The iconic stimulus activates an associated lexical code (e.g. presentation of a dog activates the word “dog”), and this lexical activation could then, through a recurrent feedback mechanism, alter the percept that triggered it in the first place. Given the assumption that lexical codes are more strongly represented in the left hemisphere, this interactive process would be more readily engaged for inputs coming from the right visual field. This account is an instantiation of interactive activation models that have been proposed in various perceptual domains such as word recognition (e.g. McClelland & Rumelhart, 1981). Applied in the current context, the activation of the word “dog” might cause the stimulus to appear as a more prototypical dog. This would make identification of the target more difficult since, by definition, instances closer to the prototype will be more similar to one another, handicapping within-category discrimination. Correspondingly, an on-line distortion of the percept in this manner would make it easier to discriminate a dog from a cat, since dogs and cats have different prototypes.

On the post-perceptual account, the percept triggers the lexical code as before, but this time, the perceptual representation itself is not affected. Instead, the lexical code and the intact perceptual representation both influence post-perceptual processes, similar to the manner in which Stroop-like stimuli either converge on similar response codes (e.g., the word “RED” in red ink) or create conflict through the activation of different response codes (e.g., the word “RED” in green ink). When the target and distractor are from the same lexical category (e.g. both “dogs”), the common lexical codes would compete with the perceptual difference, thus slowing down RTs. When the target and distractor are from different lexical categories, (e.g. “dog” and “cat”), the lexical difference would supplement the perceptual difference and thus enhance performance on cross-category discriminations.

Both of these broad accounts are consistent with the lateralized Whorf effect. In each, the activation of the lexical

codes is greater for RVF targets given the LH dominance for language. Indeed, there could be merit to both the perceptual and post-perceptual accounts. However, the psychophysics experiments reported here do not discriminate among these possibilities—nor, to our knowledge, do other existing studies in the literature.

In our earlier work with a color discrimination task, the advantage for discriminating between items from different lexical categories over ones in the same lexical category was only observed when the target was in RVF (Gilbert et al., 2006). In the current study, this advantage was present for both VFs in neurologically normal participants, albeit to a lesser degree in the LVF (see also, Drivonikou et al., 2007). One factor that may be relevant in terms of the presence of a lateralized Whorf effect in the LVF is overall response speed. The mean RTs on the color discrimination task in Gilbert et al. were around 425 ms. This is about 400 ms faster than for the cat–dog discriminations in the present experiments and between 100 and 600 ms faster than in the various experiments reported in Drivonikou et al. With fast RTs, the activation of lexical codes from LVF stimuli may be too slow to influence performance. With longer RTs, these lexical codes should have a greater opportunity to influence performance.

How might lexical access be achieved for LVF stimuli? These codes might be present, but weaker in the RH compared to the LH. Alternatively, they may become activated following transcallosal transfer, or exert their influences through a combination of these two possibilities. Interestingly, we did not observe a Whorf effect for stimuli in the LVF in the callosotomy patient. This suggests that the weak LVF effect observed in normal participants may be due to interhemispheric transfer, rather than through the engagement of RH lexical representations. On the other hand, the RH may possess a lexicon, but the organization, access and influence of these representations may differ from that associated with the LH (see Baynes, Kroll, & Dronkers, 1997; Gazzaniga et al., 1984a, 1984b; Zaidel, 1991). Patient VP has been found capable of transferring some phonological but not semantic information about visually presented words from one hemisphere to the other (Funnell, Corballis, & Gazzaniga, 2000). Thus, the lack of a Whorf effect for stimuli in VP’s LVF suggests that the effects of language on perception rely on semantic rather than phonological lexical representations.

The findings presented here document the generality of the lateralized Whorf effect, providing a first demonstration of this phenomenon in a domain other than color discrimination. As such, these results open the field to further experimentation with more complex stimulus types in which categorical structure is defined at varying levels of abstraction. Further work will be required to illuminate the psychological processes and neural mechanisms that underlie the interaction of language and perception.

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References

- Baynes, K., Kroll, N., & Dronkers, N. (1997). Contributions of the corpus callosum to semantic facilitation. *Journal of the International Neuropsychological Society*, 3, 9.
- Casasanto, D. (2005). Crying “Whorf”. *Science*, 307, 1721–1722.
- Corballis, P. M., Funnell, M. G., & Gazzaniga, M. (2002). Hemispheric asymmetries for simple visual judgments in the split brain. *Neuropsychologia*, 40(4), 401–410.
- Daoutis, C. A., Pilling, M., & Davies, I. R. L. (2006). Categorical effects in visual search for colour. *Visual Cognition*, 14, 217–240.
- Davidoff, J. (1976). Hemispheric sensitivity differences in the perception of colour. *Quarterly Journal of Experimental Psychology*, 28, 387–394.
- DeJong, R. (1993). Multiple bottlenecks in overlapping task performance. *Journal of Experimental Psychology: Human Perception and Performance*, 19(5), 965–980.
- Drivonikou, G. V., Kay, P., Regier, T., Ivry, R. B., Gilbert, A. L., Franklin, A., et al. (2007). Further evidence that Whorfian effects are stronger in the right visual field than the left. *Proceedings of the National Academy of Sciences*, 104, 1097–1102.
- Franklin, A., Clifford, A., Williamson, E., & Davies, I. (2005). Color term knowledge does not affect categorical perception of color in toddlers. *Journal of Experimental Child Psychology*, 90, 114–141.
- Frey, S. H., Funnell, M. G., Gerry, V. E., & Gazzaniga, M. S. (2005). A dissociation between the representation of tool-use skills and hand dominance: Insights from left- and right-handed callosotomy patients. *Journal of Cognitive Neuroscience*, 17(2), 262–272.
- Funnell, M. G., Corballis, P. M., & Gazzaniga, M. S. (2000). Insights into the functional specificity of the human corpus callosum. *Brain*, 123, 920–926.
- Gazzaniga, M. S., Nass, R., Reeves, A., & Roberts, D. (1984a). Neurologic perspectives on right hemisphere language following surgical section of the corpus callosum. *Seminars in Neurology*, 4, 126–135.
- Gazzaniga, M. S., Smylie, C. S., Baynes, K., Hirst, W., & McCleary, C. (1984b). Profiles of right hemisphere language and speech following brain bisection. *Brain and Language*, 22, 206–220.
- Gilbert, A., Regier, T., Kay, P., & Ivry, R. (2006). Whorf hypothesis is supported in the right visual field but not the left. *Proceedings of the National Academy of Sciences*, 103(2), 489–494.
- Gordon, P. (2004). Numerical cognition without words: Evidence from Amazonia. *Science*, 306, 496–499.
- Gordon, P. (2005). Reply to Casasanto. *Science*, 307, 1722.
- Heider, E. R. (1972). Universals in color naming and memory. *Journal of Experimental Psychology*, 93, 10–20.
- Heider, E. R., & Olivier, D. C. (1972). The structure of the color space in naming and memory for two languages. *Cognitive Psychology*, 3, 337–354.
- Kay, P., & Kempton, W. (1984). What is the Sapir-Whorf hypothesis? *American Anthropologist*, 86, 65–79.
- McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, 88, 375–407.
- Nishimura, R. (2006). The asymmetry of interhemispheric interaction in reverse-stroop task. *Shinrigaku Kenkyu*, 77(2), 163–169.
- Pashler, H. (1984). Processing stages in overlapping tasks: Evidence for a central bottleneck. *Journal of Experimental Psychology: Human Perception and Performance*, 10(3), 358–377.
- Roberson, D., & Davidoff, J. (2000). The categorical perception of colors and facial expressions: The effect of verbal interference. *Memory and Cognition*, 28(6), 977–986.
- Sidtis, J. J., Volpe, B. T., Wilson, D. H., Rayport, M., & Gazzaniga, M. S. (1981). Variability in right hemisphere language function after callosal section: Evidence for a continuum of generative capacity. *Journal of Neuroscience*, 1, 323–331.
- Simon, J. R., Paullin, C., Overmyer, S. P., & Berbaum, K. (1985). Reaction time to word meaning and ink color of laterally-presented stroop stimuli: Effects of handedness and sex. *International Journal of Neuroscience*, 28(1–2), 21–33.
- Van Selst, M., & Jolicoeur, P. (1997). Decision and response in dual task interference. *Cognitive Psychology*, 33, 266–307.
- Wada, J. A., Clarke, R., & Hamm, A. (1975). Cerebral hemispheric asymmetry in humans. Cortical speech zones in 100 adults and 100 infant brains. *Archives of Neurology*, 32(4), 239–246.
- Welford, A. T. (1952). The “psychological refractory period” and the timing of high speed performance: A review and a theory. *British Journal of Psychology*, 43, 2–19.
- Whorf, B. L. (1956). In J. B. Carroll (Ed.), *Language, thought, and reality: Selected writings of Benjamin Lee Whorf*. Cambridge, MA: MIT Press.
- Winawer, J., Witthoft, N., Frank, M., Wu, L., Wade, A., & Boroditsky, L. (2003). Russian blues reveal the effects of language on color discrimination. *Proceedings of the National Academy of Sciences*, 104(19), 7780–7785.
- Zaidel, E. (1991). Language functions in the two hemispheres following complete cerebral commissurotomy and hemispherectomy. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology* (vol. 4, pp. 115–150). Amsterdam: Elsevier.