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Short Communication

Aphasic patients exhibit a reversal of hemispheric asymmetries in categorical color discrimination

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ABSTRACT

Patients with left hemisphere (LH) or right hemisphere (RH) brain injury due to stroke were tested on a speeded, color discrimination task in which two factors were manipulated: (1) the categorical relationship between the target and the distracters and (2) the visual field in which the target was presented. Similar to controls, the RH patients were faster in detecting targets in the right visual field when the target and distracters had different color names compared to when their names were the same. This effect was absent in the LH patients, consistent with the hypothesis that injury to the left hemisphere handicaps the automatic activation of lexical codes. Moreover, the LH patients showed a reversed effect, such that the advantage of different target–distracter names was now evident for targets in the left visual field. This reversal may suggest a reorganization of the color lexicon in the right hemisphere following left hemisphere brain injury and/or the unmasking of a heightened right hemisphere sensitivity to color categories.

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1. Introduction

In a set of influential papers on linguistic relativity, Whorf (1956) proposed that the language we speak shapes our perception of the world. Support for this idea has been drawn from several research domains, including spatial relations (Majid, Bowerman, Kita, Haun, & Levinson, 2004), numerical cognition (Gordon, 2004), and most notably, color perception. For example, English speakers perceive a greater distance between colors that span a lexical boundary (“blue” and “green”) than speakers whose language does not mark that boundary with basic color terms (Kay & Kempton, 1984).

While Whorfian effects in color perception have been widely explored through cross-linguistic studies (Davidoff, Davies, & Roberson, 1999; Kay & Kempton, 1984; Roberson, Davidoff, Davies, & Shapiro, 2005; Thierry, Athanasopoulos, Wiggett, Dering, & Kuipers, 2009; Winawer et al., 2007), recent work has turned to the question of whether such effects can also be observed within individuals. Gilbert, Regier, Kay, and Ivry (2006) used a visual search task consisting of a circular display of colored squares (Fig. 1). The color of one square, the target, was different than that of the other squares, the distracters, and the participant was required to make a speeded response, indicating the side of the target. Reaction times to detect a target in the right visual field (RVF) were faster when the target and distracters belonged to different lexical categories (e.g., a green target among blue distracters) compared to when the target and distracters were from the same lexical category (e.g., a green target among distracters that were a different hue of green). This lexical effect was attenuated when the target was in the left visual field (LVF). This within-individual asymmetry, coined the “lateralized Whorf effect,” has been observed in a number of subsequent studies (Drivonikou et al., 2007; Gilbert, Regier, Kay, & Ivry, 2008; Roberson, Pak, & Hanley, 2008).

This pattern of results suggests a linguistic influence on perception that is related to the rapid access of lexical codes in the left hemisphere. This hypothesis is based on two widely accepted tenets, namely that language is generally lateralized to the left hemisphere and the initial projection of visual input is primarily processed in the contralateral hemisphere. By this view, input from the right visual field will access lexical codes faster than input from the left visual field. These lexical codes will facilitate perceptual decisions when the target and distracter are from different lexical categories and potentially handicap such decisions when the target and distracter are from the same lexical categories.

This process-based account of the lateralized Whorf effect is consistent with two additional findings in the study of Gilbert et al. (2006). First, under conditions of verbal, but not spatial interference, the lateralized Whorf effect was abolished in neurologically healthy participants. Presumably, the verbal interference task

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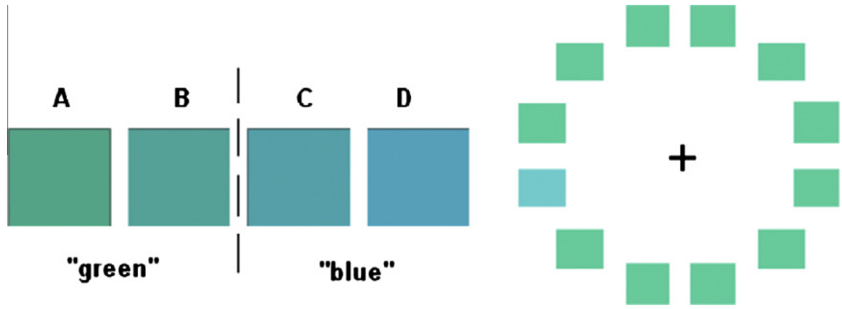

Fig. 1. Print-rendered versions of the four stimulus colors (left) and sample display of the visual search task (right). Participants pressed one of two response keys, indicating the side containing the target (oddball color), presented among an array of homogeneous distracters.

disrupted the access of the lexical codes associated with the colored squares. Second, the lateralized Whorf effect was limited to the right visual field in two callosotomy patients who were known to have language strongly lateralized to the left hemisphere. We assume that lexical representations associated with left visual field input are weakly activated in these patients, either because of a limited right hemisphere lexicon or because the callosotomy operation has eliminated direct interhemispheric communication.

In the present study, we took a different approach to examine the role of hemispheric asymmetries in the lateralized Whorf effect. Using the same visual search task as Gilbert et al. (2006), we tested patients with left hemisphere (LH) or right hemisphere (RH) brain injury due to stroke. The LH stroke patients exhibited symptoms of aphasia, with variation in terms of severity and subtype; none of the RH stroke patients were aphasic. Patients responded with the ipsilesional hand since many were hemiparetic. Two control groups were also tested, matched to their respective patient group in terms of age, education, and response hand used for the task. Based on the assumption that LH damage would disrupt the rapid access to lexical codes, we predicted that the lateralized Whorf effect would be attenuated in the LH group. Specifically, LH patients' reaction times to targets in the RVF should be comparable whether or not targets and distracters have the same color names. On the other hand, the normal lateralized Whorf effect should be present in RH patients and controls.

2. Results

The analyses presented below are limited to data from trials in which the target and distracter were neighbors in psychological space (Fig. 1: stimulus pairs AB and CD are within-category pairs and pair BC is the between-category pair). Trials in which the reaction time (RT) was greater than two standard deviations from an individual participant's mean were excluded from the analyses.

The RT results are graphed as difference scores in Fig. 2a, subtracting the mean RT of the between-category condition from that of the within-category condition. Mean RTs, collapsed over lexical relationship, are presented in Fig. 2b. We first analyzed the RT data with a 4-factor analysis of variance (ANOVA), with response hand (right vs. left) and group (patient vs. control) as between-subjects factors, and visual field (right vs. left) and lexical relationship (between-category vs. within-category) as within-subjects factors. There was a significant 4-way hand $\times$ group $\times$ visual field $\times$ lexical relationship interaction, $F(1,41) = 10.61$, $p = .002$. To understand clearly which factors contributed to this high-order interaction, we conducted a set of focused analyses. One set involved comparisons of each patient group to its respective control group. In the other set, we first compared the two patient groups and then compared the two control groups.

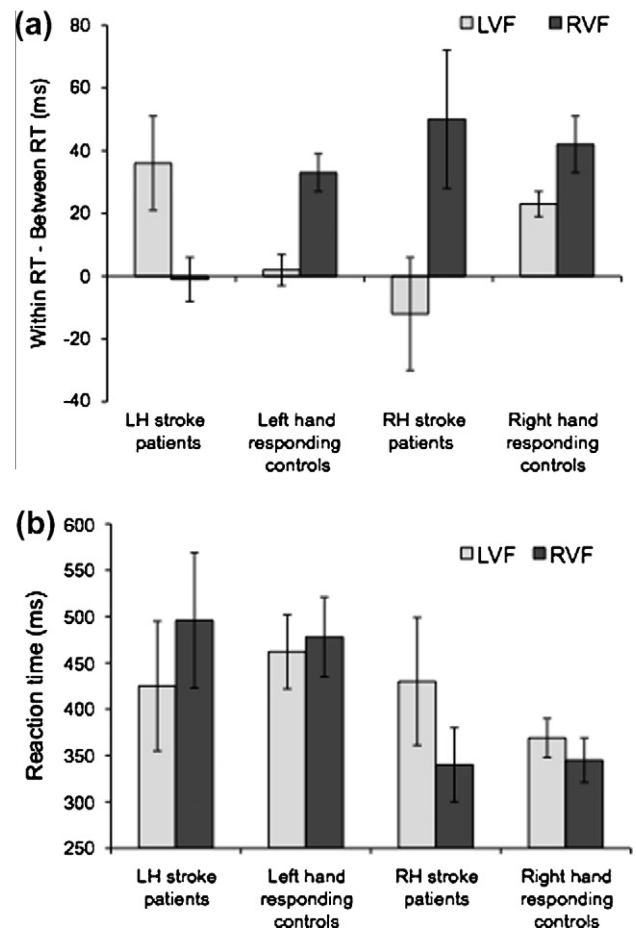

Fig. 2. (a) Difference in RT (+- SEM) for trials in which the target–distracter colors were within-category neighbors (AB and CD) or between-category neighbors (BC). Both control groups and the RH stroke patients show a RVF advantage for between-category trials compared to within-category trials. This difference is either significantly smaller or absent for LVF targets. This effect is reversed in the LH stroke patients with the between-category advantage only found for LVF targets. (b) Mean reaction time (ms) for LVF and RVF targets, collapsed over the between- and within-category conditions. LH patients and their control group responded with two fingers of the left hand; RH patients and their control group responded with two fingers of the right hand. Note that while mean RTs are faster for targets ipsilateral to the response hand in all groups, this effect is larger for both patient groups, indicative of mild contralesional neglect.

2.1. LH patients vs. controls

There was a significant 3-way group $\times$ visual field $\times$ lexical relationship interaction, $F(1,25) = 12.69$, $p = .002$. Control participants showed the lateralized Whorf effect previously observed in young adults: they were faster on between-category trials compared to within-category trials when the target appeared in the right visual field. As predicted, this effect was attenuated in the patients with LH lesions. Indeed, for RVF targets, the LH patients showed no difference in reaction time on between-category trials compared to within-category trials. Unexpectedly, these patients showed a reversal of the lateralized Whorf effect, with a reaction time advantage for LVF targets on between-category trials compared to within-category trials. Two main effects were also significant: lexical relationship [$F(1, 25) = 7.94$, $p = .009$] and visual field [$F(1, 25) = 10.05$, $p = .004$]. Overall, RTs were faster in the between-category condition (456 ms) than in the within-category condition (473 ms), and RTs were faster to LVF targets (442 ms) than to RVF targets (487 ms).

2.2. RH patients vs. controls

The 2-way visual field × lexical relationship interaction was significant, $F(1, 16) = 7.08$, $p = .017$. Both the RH patients and controls had faster reaction times on between-category trials compared to within-category trials, but only when the targets appeared in the RVF (i.e., the normal lateralized Whorf effect). Main effects were also observed for lexical relationship, [$F(1, 16) = 15.67$, $p = .001$] and visual field, [$F(1, 16) = 8.29$, $p = .011$]. Similar to the LH patients and their controls, RTs were faster overall on between-category trials (370 ms) compared to within-category trials (396 ms). However, the visual field effect was reversed with faster RTs now observed when the targets appeared in the RVF (354 ms) compared to the LVF (412 ms).

2.3. LH patients vs. RH patients

Similar to the comparison of the LH patients and their controls, the 3-way interaction was significant [$F(1, 20) = 8.64$, $p = .008$]. The RH patients showed a between-category advantage in the RVF (lateralized Whorf effect), whereas the LH patients showed a between-category advantage in the LVF (reversed Whorf effect). In addition, the group × visual field interaction was significant, [$F(1, 20) = 11.89$, $p = .003$]. Both groups were slower when responding to targets in the contralesional visual field (see Fig. 2b), consistent with the hypothesis that they exhibit mild neglect for contralesional stimuli.

2.4. Right-hand responding controls vs. left-hand responding controls

Both control groups consisted of only right-handed participants. However, one group used the right hand to respond and the other the left hand so that we could perform comparisons to the patient groups. To evaluate the effect of response hand, we directly compared the two control groups. The 2-way visual field × lexical relationship interaction was significant, $F(1, 21) = 19.99$, $p < .001$. Both groups of controls had faster reaction times on between-category trials compared to within-category trials, but only when the targets appeared in the RVF (i.e., the normal lateralized Whorf effect). We also observed a main effect for lexical relationship, [$F(1, 21) = 32.861$, $p < .001$], with RTs faster overall on between-category trials (413 ms) compared to within-category trials (439 ms).

2.5. Correlational analyses

As an exploratory tool, we calculated a series of correlations to ask if the reversed lateralized Whorf effect was related to particular measures of aphasia or neuropathology. We used two performance scores: (a) the within-category and between-category difference in RTs for the LVF and (b) the increase in the within-between difference for LVF targets compared to RVF targets, a double difference measure that captures the relative shift. For the 15 LH patients, neither lesion volume nor aphasia severity as assessed by the Western Aphasia Battery (WAB) correlated with the magnitude of the LVF between-category advantage (volume: $r = 0.09$; WAB: $r = 0.02$) or the relative increase of the between-category advantage across the visual fields (volume: $r = 0.00$; WAB: $r = 0.11$). The two performance measures were also not correlated with the number of months post-injury ($r = 0.22$ and $r = -0.15$, respectively), although all of the patients had been aphasic for at least 3 years. Given the sample size, meaningful comparisons of different subtypes of aphasia is not possible.

3. Discussion

In the current study, LH and RH stroke patients were tested on a color discrimination task used in previous research to examine the relationship of language and perception. In particular, the time to detect the position of a colored target is faster when the lexical category of the target is different from the lexical category of the distractors, but only when the targets are presented in the right visual field. In our neuropsychological extension, we found that RH stroke patients and the two control groups exhibited this between-category lateralized Whorf effect. In contrast, the LH patients failed to show this between-category advantage in the RVF. Moreover, these patients showed a visual field reversal, with the advantage for between-category trials occurring for targets in the LVF.

The effect of the lexical relationship between the target and distracters in this color discrimination task likely reflects the interaction of sensory and lexical codes (Gilbert et al., 2006). The fact that this effect is more pronounced for targets in the RVF in neurologically healthy individuals and RH patients is consistent with a wealth of evidence suggesting a prominent LH role in the representation of the mental lexicon (e.g., Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996). By this hypothesis, lexical codes in the left hemisphere interact at a relatively early stage of processing with perceptual input from the right visual field, such that between-category differences are amplified and/or within-category differences are attenuated, even in a rapid visual search task (see also, Brown, Gore, & Pearson, 1998).

The etiology of this interaction remains unclear. At one extreme, a structural account of the Whorf effect would emphasize that language has reshaped perception. By this view, the long-term interaction of lexical and perceptual codes results in altered perceptual processes that have been tuned by linguistic structure. Alternatively, by a process-oriented account, the interaction could reflect the on-line interaction of perceptual and lexical codes (Gilbert et al., 2006; Lupyan & Spivey, 2008; Roberson et al., 2008). Even though our task simply requires judging the spatial location of the target, the color names are likely to be automatically activated (see also, Richter & Zwaan, 2009). These lexical codes might interact with on-going perceptual processes or interact at decision stages of processing, similar to the manner in which Stroop interference is thought to reflect response conflict arising from the automatic activation of color names (reviewed in MacLeod, 1991).

To date, the fact that the lateralized Whorf effect is attenuated during a concurrent verbal task (Gilbert et al., 2006; Gilbert et al., 2008) has provided the strongest evidence against a structural hypothesis. A more parsimonious interpretation is that the secondary verbal task interferes with linguistic processes, thus reducing the influence of the lexical codes activated in the visual search task. A process-based account is further supported by the observation that a between-category advantage is also observed for LVF targets when reaction times are long (Roberson et al., 2008). Under such conditions, perceptual codes that were initially activated in the right hemisphere may have sufficient time, via interhemispheric communication, to interact with left hemisphere linguistic representations and/or be influenced by weaker lexical representations in the right hemisphere.

The current study provides further insight into the mechanisms underlying the lateralized Whorf effect. Analogous to the effects of a verbal secondary task, we hypothesized that injury to the LH would disrupt or slow access to a LH lexicon. As such, we predicted that the responses to RVF targets would be predominantly driven by perceptual codes. Consistent with this prediction, reaction times to RVF targets were similar on the within-category and between-category trials in the patients with LH lesions. The absence of a RVF advantage on between-category trials is striking for two reasons. First, this RVF advantage was observed in the RH patients and both control groups, providing further evidence that this effect is robust. Second, the group of LH patients had considerable variability in lesion size and aphasic symptoms, yet we did not observe any consistent relationship between these variables and performance. The results suggest that a general consequence of aphasia may be disruption of lexical access, even if the presence of overt symptoms such as anomia is highly variable. Modest impairments may suffice to eliminate the contribution of lexical codes on performance in speeded responses based on relatively simple perceptual discriminations.

The finding that the lateralized Whorf effect was not just attenuated in the LH patients, but actually reversed was unexpected. These patients exhibited a reliable between-category advantage for LVF targets. This reversal might reflect a transhemispheric reorganization of language, including the lexicon (reviewed in Hillis, 2006), given that all of the patients were tested in the chronic phase of illness, at least 3 years post-stroke. A variant of this idea is that latent RH language functions become manifest when the LH is damaged (Chiarello & Maxfield, 1996).

One argument against the reorganization hypothesis is that patients with chronic LH lesions have been shown to exhibit greater language-related activation in spared regions of the LH rather than a shift of activation to the RH (Saur et al., 2006). Interestingly, this correlate of functional recovery was most pronounced in anterior regions of the left hemisphere. In our sample, three of the patients had lesions limited to the frontal lobe. Of these, two showed the normal pattern of a lateralized Whorf effect, with the between-category advantage more pronounced in the right visual field. In contrast, 9 of the 10 patients with lesions extending into parietal and/or temporal cortex showed the reversed lateralized Whorf effect. While our sample size for such analyses is small, the present data are consistent with the hypothesis that RH linguistic functions become more prominent following left hemisphere stroke.

An alternative account, one that is not exclusive of the reorganization hypothesis, builds on previous work demonstrating implicit (or non-linguistic) processes for color categorization. Roberson, Davidoff, and Brainsby (1999) reported a case study of an aphasic patient who performed poorly on color categorization tasks that required explicit naming, but with more indirect measures, evidenced sensitivity to color categories. The current results suggest that implicit color categorization processes remain intact in the right hemisphere. Indeed, pre-linguistic infants exhibit categorical effects in the left visual field on a color discrimination task (Franklin et al., 2008a). This effect shifts to the right visual field when color naming competency emerges (Franklin et al., 2008b). Thus, when linguistic functions are limited, either in early development or through neurological insult, implicit color categorization processes are evoked, and these may be lateralized to the right hemisphere. For individuals with intact linguistic function, these implicit processes are attenuated, and in fact, may be overridden, by the rapid access of lexical codes in the left hemisphere (Fallshore & Schooler, 1995).

While the available data do not provide a clear case with respect to evaluating the reorganization and implicit categorization hypotheses, the results provide further evidence in favor of a process-based account of the interaction of language and perception. Disruption of linguistic function from left hemisphere stroke was sufficient to eliminate a right visual field advantage for rapid perceptual discriminations marked by lexical differences.

4. Methods

4.1. Participants

Participants included 15 left hemisphere (LH) stroke patients, seven right hemisphere (RH) stroke patients, and two groups of healthy controls, matched in age- and education to the patient groups. All participants were right-handed and native English speakers. Stroke patients were assessed at the Center for Aphasia and Related Disorders at the Veterans Affairs Northern California Health Care System (VANCHCS) in Martinez, CA. Patients were selected if their medical history and radiological records indicated a single cerebrovascular accident at least 1 year prior to testing and no history of other neurological injury, psychiatric disability, or substance abuse.

The LH patient group consisted of 10 men and 5 women (see Table 1). The mean age of patients was 65 years (SD = 7; range 56–81), mean education was 17 years (SD = 2; range 12–20), and mean months post-onset at time of testing was 109 (SD = 44; range 44–212). Language status was assessed with the Western Aphasia Battery (WAB; Kertesz, 1982). Aphasia classifications included Wernicke's ($n = 2$), conduction aphasia ($n = 2$), anomic aphasia ($n = 3$), and transcortical sensory aphasia ($n = 1$). Seven patients tested within normal limits on the WAB, but all patients exhibited clinical symptoms of aphasia, including some word-finding difficulties. An additional three LH patients were tested; two were excluded from the analyses due to atypical lexical color boundary placement during post-testing (see below), and one was excluded due to an inability to maintain fixation.

The RH patient group consisted of four men and three women. None of these patients exhibited any signs of aphasia. The mean age of patients was 62 years (SD = 12; range 35–72), mean education was 16 years (SD = 1; range 14–16), and mean months post-onset at time of testing was 65 (SD = 27; range 28–102). One additional RH patient was tested, but was subsequently excluded from the analyses due to atypical lexical color boundary placement.

None of the patients in either the LH or RH groups had visual field deficits. Three of the RH patients had persistent evidence of mild contralateral neglect. Six LH patients and three RH patients showed some weakness or hemiplegia in the contralateral hand. All of the patients responded with their ipsilesional hand.

Inclusion criteria for controls in the current study included no history of neurological injury, psychiatric disability, or substance abuse. Twelve of the neurologically healthy control participants were matched to the LH patients and performed the task with the left hand. This control group consisted of six men and six women. Mean age was 62 years (SD = 7; range 53–77), mean education was 16 years (SD = 2; range 12–18). One additional control participant was tested with the left hand, but excluded due to atypical lexical color boundary placement during post-testing. The other 11 control participants were matched to the RH patients and performed the task with the right hand. This group consisted of five men and six women. Mean age was 59 years (SD = 4; range 52–67), and mean education was 16 years (SD = 2; range 12–18).

The study was approved by the Institutional Review Boards at the VANCHCS and UC Berkeley. All participants signed consent forms prior to the study, according to institutional guidelines.

Table 1
Individual information for patients with left hemisphere lesions. Aphasia score is based on the Western Aphasia Battery. Scores can range between 0 and 100, with 100 indicative of normal performance. Difference scores are calculated as $RT_{within} - RT_{between}$ for each visual field.

Participant	Lesion vol (CC^{-1})	Aphasia type	Gender	Age at test	Educ. (years)	Aphasia score	Months post-onset	Difference RVF	Difference LVF
0716	85	Anomic	M	62	16	84.4	142	−75	56
0969	15	TCS	M	69	12	55.7	118	−65	51
1063	101	Conduction	M	60	14	75.1	50	−44	−132
1027	52	WNL	M	70	20	98.6	44	−27	70
0638	Not avail	WNL	M	66	14	99.4	127	−13	29
0970	146	Wernicke	M	81	16	37.1	83	−1	37
0729	38	WNL	F	68	18	95.9	102	0	34
1058	104	Anomic	F	65	18	87.1	97	12	39
0896	85	WNL	M	66	16	97.6	212	16	58
1015	182	Conduction	F	58	18	66.7	136	18	33
0997	21	WNL	F	56	17	97.4	78	25	−7
1018	2	WNL	F	58	17	99.4	62	26	69
0855	13	WNL	M	68	16	99.6	164	27	−3
0951	104	Wernicke	M	72	20	73.6	108	35	40
1029	136	Anomic	M	56	16	78.8	109	50	159
Means	77.4		10 M.5F	65.0	16.5	83.1	108.8	−1	35.5
Stan error	15.4			1.8	0.6	5.0	11.9	9.9	16.0

4.2. Materials

Four colors, forming a graded series (A–D) from green to blue were used (see Fig. 1). These corresponded to computer-generated colors selected to match Munsell values of 7.5G, 2.5BG, 7.5BG, and 2.5B. The colors were calibrated on the monitor, using software available at www.easyrbg.com. Brightness and saturation values were equated based on the independent judgments of four observers. The 8-bit RGB values for the four colors were 0,171,129 (7.5G), 0,170,140 (2.5BG), 0,170,170 (7.5BG), and 0,149,170 (2.5B). The RBG values for the background were all set to 178. Based on prior work using the same calibration procedure (Gilbert et al., 2006), the green–blue boundary was expected to lie between colors B and C.

In the visual search task, each stimulus display consisted of a ring of 12 colored squares surrounding a central fixation marker. The radius of the circle spanned a visual angle of 12°. All of the squares were the same color except for the target. The target and distracter colors were either from the same lexical category (e.g., two different shades of blue) or from different lexical categories (e.g., a green target among blue distracters). There were three types of target–distracter pairs: 1-step within-category (AB and CD), 1-step between-category (BC), and 2-step between-category (AC and BD). The analyses reported here are limited to the 1-step pairs since these pairs are of similar psychological distance for the within- and between-category conditions.

4.3. Procedure

The order of trials was counterbalanced across participants. Each trial began with the onset of a central fixation cross. After 1000 ms, the stimulus display appeared, consisting of a ring of 12 squares surrounding the fixation marker. The target appeared in each of the 12 positions on an equal number of trials. The participants were instructed to press one of two horizontally-aligned keys on the keyboard, indicating the side of the target. After the response, the screen was blank for 250 ms before the fixation marker appeared to indicate the start of the next trial. Each participant completed four 60-trial blocks.

Prior to the beginning of the test blocks, a 10-trial practice block was administered. During this block, the visual search display was visible for 200 ms. If the participant had difficulty performing the task, the duration of the stimulus presentation was increased by 100 ms in the following practice block. This method was repeated up to three times with the maximum exposure duration set to 500 ms. The exposure duration of the last practice block was used for the test blocks. The mean exposure durations for the LH and RH patients were 333 ms (SD = 111 ms) and 257 ms (SD = 79 ms), respectively. The experimenter monitored eye movements and reminded the participant to maintain fixation whenever eye movements were observed. The exposure duration was 200 ms for all of the control participants. Variation in duration of stimulus presentation was not correlated with the critical dependent measures.

Following the completion of the visual search task, each participant's blue–green lexical boundary was determined. In half of the trials of this task, a colored square (with the color set to A, B, C, or D) was presented centrally on a neutral gray screen for 200 ms. For the other half of the trials, the square was presented to the right or left of the fixation marker. Participants indicated to the experimenter whether the color was green or blue. Each stimulus was presented 20 times in a total of 80 randomized trials. Only participants who placed the blue–green lexical boundary between stimuli B and C for all three positions (left, center, right) were included in the data analyses.

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