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Shifting Attention in Viewer and Object-Based Reference Frames after Unilateral Brain Injury

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Abstract

The aims of the present study were to investigate the respective roles that object- and viewer-based reference frames play in reorienting visual attention, and to assess their influence after unilateral brain injury. To do so, we studied 16 right hemisphere injured (RHI) and 13 left hemisphere injured (LHI) patients. We used a cueing design that manipulates the location of cues and targets relative to a display comprised of two rectangles (i.e., objects). Unlike previous studies with patients, we presented all cues at midline rather than in the left or right visual fields. Thus, in the critical conditions in which targets were presented laterally, reorienting of attention was always from a midline cue. Performance was measured for lateralized target detection as a function of viewer-based (contra- and ipsilesional sides) and object-based (requiring reorienting within or between objects) reference frames. As expected, contralesional detection was slower than ipsilesional detection for all patients. More importantly, objects influenced target detection differently in the contralesional and ipsilesional fields. Contralesionally, reorienting to a target within the cued object took longer than reorienting to a target in the same location but in the uncued object. This finding is consistent with object-based neglect. Ipsilesionally, the means were in the opposite direction. Furthermore, no significant difference was found in object-based influences between the patient groups (RHI vs. LHI). These findings are discussed in the context of reference frames used in reorienting attention for target detection.

Keywords

Attention; Space; Objects; Neglect; Reference Frames; Brain Injury

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Introduction

A common problem following unilateral brain injury is an inability to orient or attend to items appearing on the contralesional side of space (Driver & Vuilleumier, 2001; Halligan & Marshall, 1998; Heilman & Valenstein, 1979; Rafal, 1994). Such contralesional deficits in attention are clinically referred to as unilateral neglect and are most flagrant immediately following brain injury. However, sensitive tests can reveal persisting contralesional deficits in attention many months or even years after neurological insult (Deouell, Sacher & Soroker, 2005; List et al., 2008; Rengachary, d'Avossa, Sapir, Shulman & Corbetta, 2009; Schendel & Robertson, 2002).

Interestingly, neglect can occur in a variety of spatial reference frames. For instance, in viewer-based reference frames, awareness of stimuli on the contralesional side of the trunk, head and/or eye midline is impaired compared to stimuli on the ipsilesional side (e.g., Bisiach, Capitani & Porta, 1985; Behrmann, Ghiselli-Crippa, Sweeney, Di Matteo & Kass, 2002; Karnath, Schenkel & Fischer, 1991). Viewer-based neglect has been dissociated from neglect in other reference frames, such as neglect defined by the gravitational environment (e.g., Calvanio, Petrone & Levine, 1987; Ladavas, 1987) or, most relevant to the current study, objects (e.g., Baylis, Baylis & Gore, 2004; Behrmann & Tipper, 1999; Driver, Baylis, Goodrich & Rafal, 1994; Driver & Halligan, 1991; Gainotti, Messerli & Tissot, 1972; Marshall & Halligan, 1993a; 1993b; McGlinchey-Berroth, Bullis, Milberg, Verfaellie, Alexander & D'Esposito, 1996; Tipper & Behrmann, 1996). Neglect can manifest in objects with canonical orientations, like a clockface (Marshall & Halligan, 1993a), or when objects are aligned such that they appear to "point" in a particular direction (Driver et al., 1994). In such cases, the part of the stimulus that is neglected is defined by the principal axes, or assumed upright orientations of the objects, as opposed to their positions in viewer-based space. For example, the contralesional side of an object could be neglected whether it is presented contralesionally or ipsilesionally in viewer-based coordinates. This class of impairments is referred to as object-based neglect because the reference frame for neglect is centered on the space defined within the object.

Object-based modulations of attention have also been demonstrated in healthy individuals. For example, a classic study by Duncan (1984) demonstrated that reporting two features from one object was superior to reporting two features from two different (albeit spatially overlapping) objects. Another hallmark study revealing the influence of objects on attention was introduced by Egly, Driver and Rafal (1994) using a variant of a standard cueing method (Posner, 1980). In Egly, Driver and Rafal's study, two parallel rectangles (objects) were presented on either side of a fixation (either horizontally- or vertically-oriented). On each trial one end of one of the rectangles was cued followed by a target either at the cued location, at the opposite end of the cued object, or at an equidistant position in the uncued object. In addition to faster response times (RTs) to targets at cued positions, RTs to targets at uncued positions were faster when the target appeared within the cued object than when it appeared within the uncued object.

In addition to the seminal observation that objects affect the distribution of spatial attention in healthy individuals, Egly, Driver and Rafal (1994) used the same approach to examine object-based attention in patients with posterior parietal injury. They found a normal pattern of object-based orienting in a group of eight right hemisphere injured (RHI) patients, but abnormal object-based orienting in a group of five left hemisphere injured (LHI) patients. LHI patients showed an abnormally large object-based effect contralesionally (in the right visual field; VF), and no object-based effect ipsilesionally (in the left VF). Their results were supported by data from a split-brain patient (Egly, Driver, Rafal & Starrveveld, 1994), who showed normal object-based orienting effects in the right VF, which were absent in the left VF. Together, the studies suggest that intact left posterior parietal areas are necessary for typical patterns of object-based orienting to emerge.

As noted above, lateralized information is asymmetrically processed by unilaterally-brain injured individuals. If cues are used to manipulate attention, then presenting cues at lateralized positions may result in disparate effectiveness of the attentional manipulation in each visual field (e.g., Vivas, Humphreys & Fuentes, 2006). When presented with lateralized cues, patients may be less, or less often, aware of a cue's presence, or even when aware, may be unable to fully use its predictive value when presented in the contralesional visual field. Contributing even further to this processing asymmetry is the tendency for neglect patients to be hyperattentive to the ipsilesional side of space (i.e., disengage deficit; Losier & Klein, 2001; Olk, Hildebrandt & Kingstone, 2010; Posner, Walker, Friedrich & Rafal, 1987; Rastelli, Funes, Lupiañez, Duret & Bartolomeo, 2008). It is therefore likely that the findings of Egly, Driver and Rafal (1994) reflect the contributions of both asymmetric cue and asymmetric target processing deficits. In the present study, we re-examined the influence of object- and viewer-based reference frames on attention using a design that presented cues at midline, a relatively unaffected position. Adopting this approach enabled a more transparent measure of the influence of object- and viewer-based reference frames on shifts of attention after unilateral brain injury.

Experiment

Methods

Participants—This study had IRB approval from both VA NCHCS as well as the Committee for Protection of Human Subjects at the University of California Berkeley. Twenty-nine patients were recruited from the Bay Area, CA community (details reported in Table 1). All patients were at least three months post injury at the time of testing (average delay median=2.01, mean=2.38, SD=1.86 years). All provided informed consent prior to participation and were financially compensated $12/hour for their participation. Inclusion criteria were: Single unilateral lesion, full visual fields in both eyes (tested via confrontation), and willingness to volunteer. Exclusion criteria were: Recent history of substance abuse (within three years), co-existing neurological diseases, and need for an English language interpreter. Thirteen patients had LHI and sixteen patients had RHI (Figure 1 shows the lesion overlap from 21 patients in whom brain scans were available). The LHI and RHI patient groups did not differ in age, lesion volume[1], delay since injury or sex.

Apparatus—Presentation software (NeuroBehavioral Systems, www.neurobs.com) was used to present stimuli and record responses. Patients were given a mouse for responses, and experimenters used an external keypad for input.

Visual stimuli were presented on a 21×33 cm laptop LCD screen. The refresh rate was 60 Hz and a resolution of 1280×768×32 was used. Sounds were presented through the laptop speakers.

Stimuli—Figure 2 illustrates the visual stimuli used. All stimuli were displayed on a light gray background, and all line widths were fixed at 0.2°. The central fixation consisted of two intersecting perpendicular 0.4° black lines, oriented vertically and horizontally. Two rectangles were oriented obliquely at ±45° from vertical, equally distanced from fixation (similar to Jordan and Tipper, 1999). The outer edges of the rectangles were 9.1° apart. Each middle gray rectangle outline was 2.4° × 9.1°. Black 45°-rotated square outlines subtending

[1]For those 21 patients in whom we do have lesion volume estimates, no volume difference was found between LHI and RHI patients, $|t|(19)<1$.

2.6° × 2.6° served as cues. Cues outlined the rectangle ends. Cues were presented only on the vertical meridian, centered 4.7° above or below fixation (center-to-center), always centered at the end of one of the two rectangles. Filled blue 1.6° × 1.6° 45°-rotated square targets were presented centered at either end of either rectangle, ±4.7° vertically or horizontally from fixation (center-to-center). Targets were positioned within the rectangle boundaries. All targets and cues were equidistant from fixation, and all lateralized targets were equidistant from the cues.

The 500-ms alerting beep was a 700-Hz tone, which ramped on and off over 20 ms, presented at approximately 60 dB SPL.

Procedure—All patients were seated approximately 60 cm from the screen with their vertical body midline aligned to the vertical midline of the screen. Patients responded by pressing the left mouse button using their dominant hand.

At the beginning of the experiment, instructions were presented on the monitor, which the experimenter read aloud. Patients were asked to fixate the center of the screen. They were informed that a black cue would indicate the most likely position of the target. They were instructed to respond as quickly as possible when they detected a blue target, regardless of where the target appeared and to withhold responses when no target appeared. The experimenter then demonstrated two sample trials (one cued and one uncued trial, described below), indicating the fixation, the cue and the target. When it was clear that the patient understood the instructions, the experimenter began the 24-trial practice block. Four experimental blocks followed, each with 120 randomized trials. Patients were given breaks between blocks.

Trials began with a 500-ms alerting beep. After 100 ms of auditory stimulation, the fixation display (the fixation and two rectangles) was presented for 600 ms. A cue was then presented for 100 ms. After another 500 ms of the fixation display, on target-present trials, a target appeared for 130 ms. Patients were given up to 1880 ms to respond. Responses or timeouts ended the trial. An 800-ms blank and silent inter-trial interval elapsed between trials (Figure 2).

During the experiment, the experimenter monitored patients' eye position for fixation. If an eye movement away from the fixation was detected, the experimenter marked the trial with a key press (to be discarded from analysis).

Design—The factors that were manipulated included cue position (top, bottom), target position (top, bottom, left, right, none), and rectangle orientation (±45° from vertical). Target conditions were coded relative to the cue preceding it (Figure 2, inset). Of the target-present trials, 64% were presented at the cued position. The remaining 36% of target-present trials were equally divided among the three uncued positions (12% each).

All cues were presented on the vertical meridian, to increase the likelihood that cues were uniformly processed regardless of the side of the patient's lesion. Targets appearing at midline positions could therefore appear at either the cued position or at an uncued position located on the opposite side of fixation along the vertical axis. In contrast, all lateralized targets were presented on the horizontal meridian and appeared at *uncued* locations, positioned within either the cued or uncued object (Figure 2). Thus, lateralized targets required attention to shift either leftward or rightward in viewer-based coordinates, and either *within* or *between* objects in the display. Importantly, distance was held equal for all lateralized shifts of attention whether attention shifted within or between objects, and regardless of the viewer-based direction of the shift. Note that viewer-based right and left were re-coded as ipsilesional or contralesional depending on the side of the patient's lesion.

Analysis and Results—For each patient, mean RTs were calculated for accurate detections (hits) for each condition. Trials with RTs outside 3 SDs of each patient's mean RT were excluded (exclusion M=1.9% of trials), as were trials with eye movements (exclusion M=0.11% of trials). Three separate ANOVAs were carried out, and are described below. Alpha level was set to 0.05.

No-target catch trials (16.67%) were used to calculate false alarm rates (M=3.8%, SD=5.6%), which did not differ between RHI and LHI groups (M_{RHI}=4.3%, M_{LHI}=3.2%; $|t|<1$). Missed target rates were also low (M=4%). Across all conditions, RHI patients missed 4.8% more targets than LHI patients: $t(27)=2.25$, $p<0.05$ (M_{RHI}=6.0%; M_{LHI}=1.3%). For each of the RT analyses described below, identical analyses were carried out on miss rates. Barring the group difference (RHI>LHI misses), no other factors or interactions reached significance.

Effectiveness of Cues

First, a RT analysis only for midline targets was conducted to confirm that, even though only 64% predictive, cues were effective. RTs to midline targets were analyzed using a mixed-model ANOVA with injured hemisphere (LHI, RHI) as a between-subjects factor and cueing (cued, opposite) as a within-subjects factor. As expected, patients were significantly faster to detect cued vs. uncued opposite targets [M_{cued} = 489 ms, M_{opp} = 510 ms; Δ = 21 ms, $F(1,27)=6.05$, $p<0.05$]. Thus, patients were sensitive to the predictability of the cue. Moreover, there was no reliable interaction between injured hemisphere and cueing [$F(1,27)=1.08$, $p=0.3$], nor was there a reliable main effect of injured hemisphere: $F(1,27)=1.63$, $p=0.2$.

Viewer- and Object-Based Effects on Lateralized Target Detection

To examine the influence of viewer- and object-based reference frames on visual attention, RTs to all lateralized targets were entered into a mixed-model ANOVA with injured hemisphere (RHI, LHI) as a between-subject factor, and VF (contralesional, ipsilesional) and object (within, between) conditions as within-subject factors.

Injured Hemisphere—Overall, there was a non-significant RT difference between LHI and RHI patients: $F(1,27)=2.3$, $p=0.14$. The injured hemisphere did not interact with any other factors: all Fs<1.

Viewer-based Effects—As expected, there was a significant main effect of visual field: $F(1,27)=22.23$, $p<0.001$. Overall, patients were 44 ms slower to shift attention to targets presented in the contralesional vs. ipsilesional VF. Thus, patients showed the expected viewer-based contralesional impairment (Figure 3; Table 1).

Object-based Effects—Object condition was not reliable overall [$F(1,27)=1.22$, $p=0.28$], but was found to interact significantly with VF (below).

Viewer- by Object-based Interaction—There was a significant VF by object interaction: $F(1,27)=5.27$, $p<0.05$. In order to characterize the two-way interaction, we separately evaluated the degree of viewer-based neglect, i.e., the degree of contralesional vs. ipsilesional RT impairment, for trials when attention was shifted within or between objects. Neglect was present in both object conditions. The two-way interaction resulted from greater viewer-based neglect when attention shifted *within* an object [62 ms, $t(28)=5.14$, $p<0.001$;

compare dark bars in Figure 3], compared to when attention shifted *between* objects [26 ms, $t(28)=2.21$, $p<0.05$; compare light bars in Figure 3].

The same interaction can be characterized in terms of how objects affected attentional orienting in the contralesional and ipsilesional VFs. Specifically, in the ipsilesional VF, RTs were 10 ms *faster* when attention had to shift within vs. between objects. Although not statistically reliable [$t(28)=1.24$, $p=0.22$], this pattern is consistent with the object-based facilitatory effects reported in healthy individuals by Egly, Driver and Rafal (1994) and many others. Interestingly, this pattern reversed in the contralesional VF. Here, patients were 26 ms *slower* when attention had to shift within (vs. between) objects: $t(28)=2.17$, $p<0.05$ (Figure 3; Table 1). This finding was reliable and indicative of object-based neglect. Interestingly, the degree of contralesional object-based neglect and ipsilesional object-based facilitation was not related within an individual [Pearson $r(27)= -0.13$], nor was there a relationship between the degree of viewer-based neglect as measured within- and between-objects [Pearson $r(27)= 0.17$].

Object-Based Effects on Midline Target Detection

Given the presence of object-based neglect in the contralesional field that was not present in the ipsilesional field, we investigated the influence of object-based reference frames at the viewer-based midline. If object-based neglect is modulated by the viewer-based reference frame this predicts that object-based neglect should manifest in milder form at midline than in the contralesional field. This prediction was tested by examining trials from only the uncued opposite target location. One condition included the trials in which the midline target appeared in the contralesional side of the object. The other condition included trials in which the target appeared in the ipsilesional side of the object. Here, the contralesional and ipsilesional *sides* refer to the target's position within an *object-centered* reference frame (Figure 4's inset).

RTs to the uncued opposite targets along the vertical midline (see Figure 2, all positions labeled 'O' in the inset) were submitted to a mixed model ANOVA with injured hemisphere (LHI, RHI) as a between-subjects factor and object-based side (contralesional, ipsilesional) as a within-subjects factor. Note that the contralesional and ipsilesional sides in object-based reference frames are undifferentiated in viewer-based ones.

Injured hemisphere was not reliable: $F(1,27)=2.16$, $p=0.15$ (RHI = 538 ms; LHI = 479 ms), nor was the interaction between injured hemisphere and object-based side: $F<1$. Mean RTs were moderately slower for the contralesional vs. the ipsilesional side of an object: 517 vs. 503 ms, respectively (Figure 4). This difference did not reach significance: $F(1,27)=3.0$, $p=0.09$. As was hypothesized based on the lateralized target data, in which a reliable 26 ms object-based contralesional neglect reversed to non-significant 10 ms object-based facilitation ipsilesionally, here we found a 14 ms trend for object-based neglect at midline. This midline result lies intermediate (both statistically and in magnitude) to the lateralized results, and further supports the notion that viewer-based reference frames interact with object-based reference frames in the reorienting of visual attention.

Discussion

This study was designed to explore the respective roles of object- and viewer-based reference frames in reorienting attention into the contralesional and ipsilesional visual fields. To do so, we tested 29 patients with unilateral brain injury in a modified version of a cueing experiment introduced by Egly, Driver and Rafal (1994). Here, objects (rectangles) were presented obliquely with cues always presented at midline (half above and half below central fixation). This approach avoids potential left/right asymmetries due to the initial orienting of attention to a lateralized cue. Targets that were presented laterally in the contralesional or ipsilesional visual fields allowed us to isolate viewer- and object-based influences on the reorienting of attention.

First, patients were successful in using the cues' predictability, as indicated by faster responses to cued vs. uncued targets along the midline. Second, target detection in lateral positions revealed both viewer- and object-based effects on attentional reorienting. A viewer-based contralesional impairment, relative to ipsilesional, was found, i.e., neglect. Notably, the degree of viewer-based neglect interacted with object-based shifts of attention. Specifically, contralesional viewer-based neglect was worse when attention was reoriented within- compared to between- objects, even when these required metrically and directionally equivalent shifts.

This pattern of performance could result from *remapping* of spatial deficits onto multiple reference frames (consistent with, e.g., Behrmann & Tipper, 1999). The current study, in particular, represents a case in which static object- and viewer-based reference frames jointly influenced reorienting of visual attention after unilateral brain injury. Interestingly, this pattern was similar whether patients suffered left or right hemisphere brain injury2. In addition, these findings suggest that *reorienting* attention into the contralesional visual field may be facilitated when attention can be released from one object, and shifted to another. This bears clinical relevance for rehabilitating neglect because it suggests that training patients to attend to a new object when shifting attention contralesionally may ameliorate their neglect.

With regard to object-based attention, it is clear from both the current study and Egly, Driver and Rafal's (1994) study that objects can influence visual-spatial attention subsequent to unilateral brain injury, as object-based attention effects were found in both LHI and RHI patients in both studies. The primary difference between the current findings and those of Egly et al. (1994) is that they observed an interaction between the side of brain injury and contralesional object-based effects, whereas we did not ($F<1$). One notable difference is that we presented cues at midline to avoid asymmetric processing of cues, which enabled us to isolate reorienting of attention into the contralesional and ipsilesional visual fields. (For a more detailed comparison between studies, see the Appendix). Nevertheless, the studies converge to reveal both viewer-and object-based sensitivities, whether after left or right hemisphere injury.

The present study contributes to the existing literature by providing further evidence that object information can be utilized despite severe spatial deficits. Neuropsychological studies have reported ameliorations in performance due to the presence of an object crossing the midline (e.g., Grossi, Lepore, Esposito, Napolitano, Serino & Trojano, 1999; Halligan & Marshall, 1991; Mattingley, Davis & Driver, 1997). In these studies, when stimuli are presented within the boundaries of an object, contralesional performance is improved. In the present study, performance is improved when participants are required to reorient from one object into another (rather than within an object). Whether performance is ameliorated by reorienting from one object into another or by reorienting within one central object, both findings confirm that object information can be utilized despite impaired visual spatial awareness. Thus, the presence of an object or a group of objects (preattentively) influences the distribution of an attentional deficit (e.g., Boutsen and Humphreys, 2000; Brooks, Wong & Robertson, 2005; Driver, 1995; Driver, Baylis & Rafal, 1992; Gilchrist, Humphreys, & Riddoch, 1996; Grabowecky, Robertson & Treisman, 1993; Mattingley et al., 1997; Pavlovskaya, Sagi, Soroker, & Ring, 1997; Ward, Goodrich, & Driver, 1994).

[2]Note, however, that lesion distribution for LHI and RHI was not mirror symmetric (Figure 1 and Table 1).

In our study, contralesional and ipsilesional object-based effects were not related within an individual, indicating that object-based sensitivity is not uniform across viewer-based space. The present findings also emphasize the need to include patients with LHI, as well as those with RHI in future studies examining interactions between objects and visual spatial attention deficits. In addition, the use of the present midline cueing approach together with finer anatomical analyses (e.g., voxel-based lesion symptom mapping, Bates, et al., 2003) will allow a better assay of the relationship between neuroanatomical loci and viewer- and object-based attentional reorienting.

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Appendix

In this appendix, we detail methodological differences between the present study and Egly, Driver and Rafal's (1994) study. As appropriate, we provide further analyses assessing the possible contribution to differences between the studies' results. Although it is unlikely that these factors underlie the differences between studies, we detail them here for completeness.

In the present study, we tested a larger number of patients (N_{LHI}=13 and N_{RHI}=16) than did Egly, et al. (1994; N_{LHI}=5 and N_{RHI}=8), and the present group of patients was more evenly divided between the sexes (11 women and 18 men vs. 1 woman and 12 men: $t(40)=2.1$, $p=0.05$). This difference could prove important given that, at the population level, men and women can display different, and sometimes opposite, cerebral lateralization of function (e.g., Cahill, 2006; McGlone, 1978; McGlone, Losier & Black, 1997; Voyer, 1996). However, this possibility was not borne out in our data: the interaction between sex, injured hemisphere and object condition was not significant: F<1. Age did not significantly differ between studies: t(40)=1.15, p=0.26; M_{EDR} = 58 years; $M_{current}$ = 63 years. The ratio of LHI to RHI patients was comparable across studies (0.38 and 0.44 LHI in Egly, et al.'s [1994] and the current study, respectively). Lastly, in the current study, we did not restrict patient inclusion to those with parietal injury as did Egly, Driver and Rafal (1994). To address this, we identified a subset of the current patients in whom we could confirm parietal damage (N_{LHI}=7; N_{RHI}=6), and performed the same analysis on RTs (injured hemisphere by viewer-based and object-based reference frames). This analysis revealed no reliable effects apart from the expected ipsilesional (vs. contralesional) VF advantage, i.e., viewer-based neglect. No statistically reliable interactions with injured hemisphere were observed in this analysis (all Fs≤1.7).

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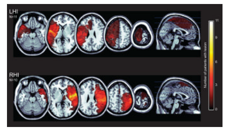

Figure 1.
Lesion overlap from those 21 patients with available brain scans (LHI=left hemisphere injury, top panel; RHI=right hemisphere injury, bottom panel). The level of each axial slice is indicated by a blue horizontal line crossing the mid-sagittal slice (far right). The right hemisphere is displayed on the right side of the figure.

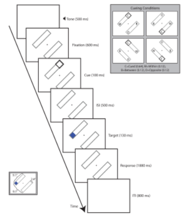

Figure 2.

Illustration of a trial sequence, stimulus dimensions and cueing conditions (inset). The tone and fixation display partially overlapped for 400 ms, with a 100 ms stimulus onset asynchrony between them.

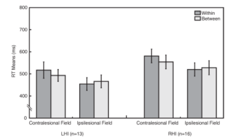

Figure 3.
RT data to targets presented laterally in the contralesional or ipsilesional VFs, requiring attention shifts within or between objects, for LHI or RHI patients. Error bars=SEM, and do not reflect statistical reliability for within-subjects comparisons.

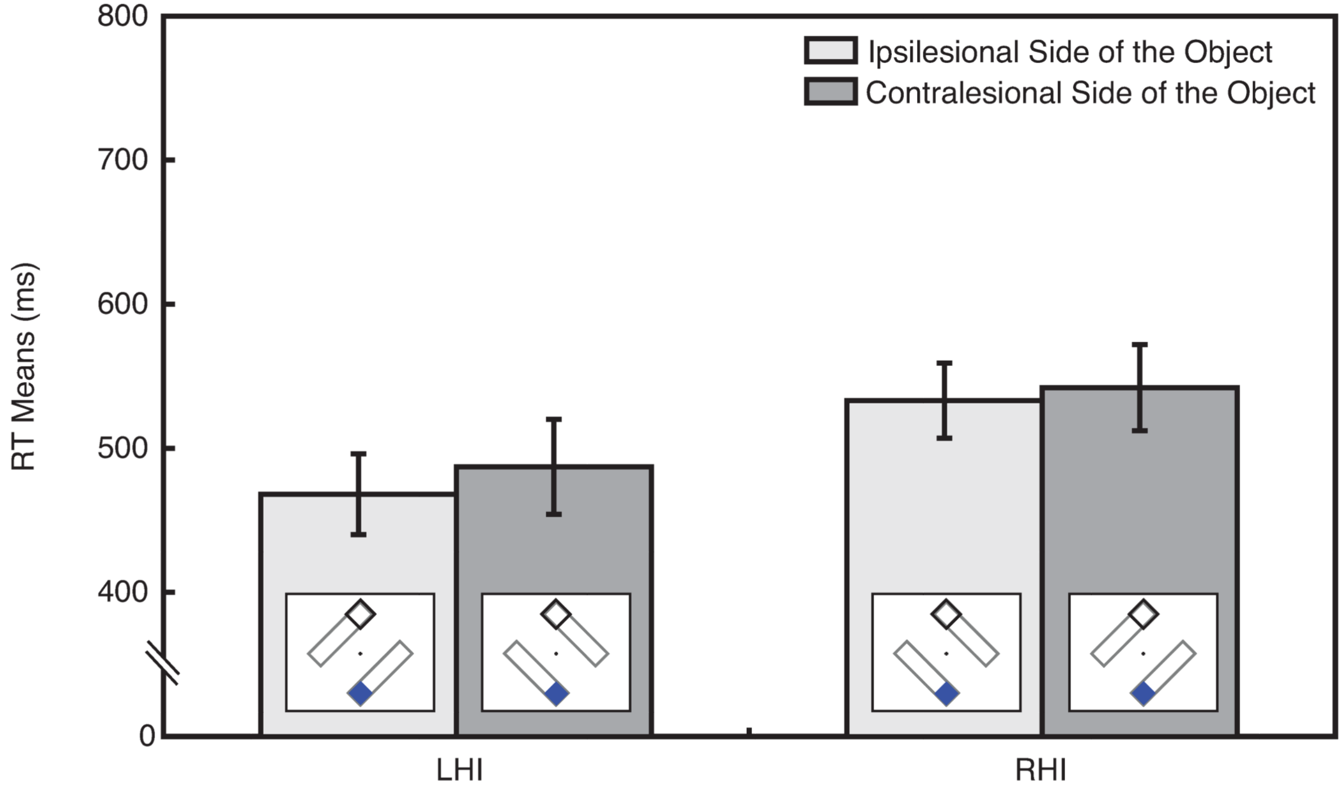

Figure 4.
RT data to targets presented in midline opposite conditions according to object side (contralesional or ipsilesional). Relevant displays are shown for LHI and RHI patients separately. Inset of display configuration depicts trials in which cues appeared in the top location (in other included trials, cues appeared in the bottom location). Error bars=SEM, and do not reflect statistical reliability for within-subjects comparisons.

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Table

Patient	Hemi	Sex	Age (y)	Hand	Lesion Site	Etiology	Vol (cc)	Delay (d)	VBN (ms)	cOBE (ms)	iOBE (ms)
PT1	L	F	35	R	BG	CVA-I		1059	5.0	−0.3	46.2
PT2	L	F	60	R	P		188.6	273	−126.3	−141.7	13.3
PT3	L	F	68	R	P, T	CVA-I	140.4	1007	−73.3	60.9	17.2
PT4	L	F	77	R	I (poss.), Put, Tp		12.8	168	−65.9	−35.7	24.8
PT5	L	F	80	R	subinsular region	CVA		195	35.7	−40.2	55.5
PT6	L	M	45	R	I, T, subcortical (us)	CVA-H	20.9	659	−32.9	−7.0	31.6
PT7	L	M	45	R	F, P, T	CVA-I	254.8	1306	−115.9	37.5	−29.9
PT8	L	M	47	R	F, I, P, T, fusiform	CVA-I	197.5	1171	−46.2	30.9	−4.1
PT9	L	M	49	R	ant. T, F oper., I		44.9	278	−47.0	−66.5	35.5
PT10	L	M	55	L	P, T	CVA-I	49	1875	−30.7	4.6	1.6
PT11	L	M	63	L	FEF, O, P	CVA-I	7.1	902	−21.0	0.0	−1.6
PT12	L	M	71	R	F, P	CVA-I	10.3	1303	−29.9	−4.0	7.8
PT13	L	M	75	R	IC, O at., P at.			238	−40.4	−153.3	−37.0
PT14	R	F	51	R	BG, IC	SAH	3.2	2063	20.2	−4.5	1.8
PT15	R	F	53	L	FEF, midbrain, brainstem	CVA-H	9.8	1046	−65.7	3.2	−64.7
PT16	R	F	60	R	F, P, T	CVA-I	183.1	1727	−77.3	9.9	80.7
PT17	R	F	64	R	F, P, T	CVA-I (x2)	310.7	1951	−134.1	−44.9	−2.6
PT18	R	F	71	R	F, WM			340	−1.6	−54.5	34.9
PT19	R	F	84	R	BG, C	SAH		227	−66.9	−25.2	−83.4
PT20	R	M	57	R	BG, I, T	CVA-H	79	265	−37.0	2.5	53.9
PT21	R	M	58	R	BG, EC, I	CVA-H	13.5	119	−35.9	−5.8	27.5
PT22	R	M	58	R	Cm, F, I, T, ACA terr.			154	−59.7	19.8	−12.1
PT23	R	M	60	L	BG, Pontine lacune, WM	CVA-H		557	58.0	−79.1	80.2
PT24	R	M	68	Ambi.	BG, F, P, T, Th	CVA	207.9	2493	−49.5	−7.9	−14.8
PT25	R	M	69	R	F, T, I, Cm		51.6	1330	−11.7	28.5	−55.9
PT26	R	M	71	R	F, P, T	CVA-I	187.1	1189	−143.7	34.3	93.2
PT27	R	M	75	R	P, T	CVA-H	178.4	231	−94.9	−244.0	59.1
PT28	R	M	75	R	Th-P	CVA-H	0.1	311	12.1	−59.8	−34.6
PT29	R	M	78	R				739	−4.4	−7.0	−28.5

Patient	Hemi	Sex	Age (y)	Hand	Lesion Site	Etiology	Vol (cc)	Delay (d)	VBN (ms)	cOBE (ms)	iOBE (ms)
Mean			63				102	868	−44.2	−25.8	10.2
SD			12				98	679	49.4	64.2	44.1

Note. Blank cells indicate that data were not available. Lesion site and etiology are given with as much detail as was obtainable. Hemi = injured hemisphere (L=left, R=right); Sex (F=female; M=male); Age = age at time of testing (years); Hand = handedne ss; Lesion site and etiology abbreviations: ACA=anterior cerebral artery; ant.=anterior; CVA= cardio -vascular accident (-I = ischemic, -H=hemorrhagic); BG=basal ganglia; C=caud ate; Cm=cingulum; EC=external capsule; F=frontal lobe; FEF=frontal eye field; I=insula; IC=internal capsule; O=occipital lobe; oper=operculum; P=parietal lobe; poss.=possible; Put=putamen; SAH=sub -arachnoid hemorrhage; T=temporal lobe; terr.=territory; Th=Thalamus (-p=Pulvinar nucleus); Tp=temporal pole; us=unspecified; WM=white matt er. Vol = lesion volume (cubic centimeters); Delay = Testing delay post stroke (days); VBN = Viewer -based neglect, computed by subtracting contralesional RTs from ipsilesional RTs (negative numbers indicate neglect); cOBE = contralesional object -based effect, computed by subtracting contralesional within- RTs from between-object RTs (negative numbers indicate object -based neglect); iOBE = ipsilesional object -based effect, computed by subtracting ipsilesional within- RTs from between-object RTs (positive numbers indicate object-based facilitation).