Consciousness and Cognition 19 (2010) 186–197

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

The imbalance of oculomotor capture in unilateral visual neglect

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ARTICLE INFO

Article history:
Received 2 September 2009
Available online 8 December 2009

Keywords:
Unilateral visual neglect
Visual attention
Eye movements

ABSTRACT

Visual neglect has been associated with an imbalance in the level of activity in the saccadic system: activity in the contralesional field is suppressed, which makes target selection unlikely. We recorded eye movements of a patient with hemispatial neglect and a group of healthy participants during an oculomotor distractor paradigm. Results showed that the interfering effects of a distractor were very strong when presented in her ipsilesional visual field. However, when the distractor was presented in her contralesional field, there were no interfering effects when the target was presented in her ipsilesional field. These findings could not be explained by the presence of a visual field defect as revealed by the results of two hemianopic patients. Our results are in line with an imbalance in the level of activity in the saccadic system in visual neglect because visual elements presented in the contralesional field did not compete for saccadic selection.

1. Introduction

Unilateral visual neglect is the failure to report, respond to, or orient to novel or meaningful stimuli presented in the contralesional visual field. This failure cannot be attributed to motor or sensory defects (Heilman & Valenstein, 1979) and is commonly found after lesions to the inferior parietal lobe,[2] in particular to the right hemisphere (Driver & Mattingley, 1998; McGlinchey-Berroth, 1997). It is generally agreed that neglect reflects lateralized impairments of attention, but the exact nature remains controversial. Kinsbourne (1987) emphasized the inability to direct attention to the contralesional hemispace, whereas Marshall and Halligan (1989) accentuated extreme capture of information in the ipsilesional hemispace. Despite the lateralized impairments of attention, preserved processing of information in the neglected field has been demonstrated in, for instance, semantic priming experiments in which stimuli presented in the neglected field were processed to a categorical level of representation (Berti & Rizzolatti, 1992; Làdavas, Paladini, & Cubelli, 1993).

One way in which attentional deficits in visual neglect can be investigated, is using eye movement paradigms. Walker and Findlay (1996) used a paradigm in which two targets were presented simultaneously and bilaterally in both hemifields of neglect patients. The two target squares appeared at equal and opposite eccentricity locations. Results showed that saccades were dominantly executed to the ipsilesional target (Walker & Findlay, 1996). Furthermore, saccade latencies to the ipsilesional target were not increased by the presence of the contralesional target, which is inconsistent with observations in nonclinical groups in which latencies are longer when participants have to saccade to one of two targets compared to when there is only one target (Levy-Schoen, 1969; Walker & Findlay, 1996; Walker, Kentridge, & Findlay, 1995). This typical increase in saccade latency is generally associated with the process of deciding which target to fixate. These findings led Walker and

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[1] Both authors have put an equal amount of work in this project and therefore regard this as a shared first authorship.

[2] Note that it has been claimed that lesions to the superior temporal cortex are crucial for observing unilateral visual neglect (Karnath, 2001). This ongoing debate, however, does not directly influence our line of reasoning and our interpretation of the results.

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doi:10.1016/j.concog.2009.11.003

Findlay (1996) to hypothesize that visual neglect might be associated with an imbalance in the level of activity in the saccadic system. Activity in the contralesional visual field is permanently suppressed which makes it unlikely for elements in that part of the visual field to compete for saccadic selection (i.e. to be a potential target for the next eye movement).

Models of eye movement generation generally assume that the saccadic competition evoked by an element is determined by the activity this element evokes on a visual field map (e.g. the superior colliculus, Trappenberg, Dorris, Munoz, & Klein, 2001). When a part of this map is suppressed due to the presence of hemispatial neglect, elements presented in the neglected (suppressed) hemifield evoke less activity compared to elements presented in non-neglected parts of the ipsilesional hemifield. Therefore, the competition induced by elements in the suppressed part is automatically weaker compared to elements in other parts of the map.

In the current study, we investigated the possible imbalance in the saccadic system in visual neglect with an oculomotor distractor paradigm. In this paradigm, saccade latencies to a target are longer when an irrelevant salient distractor is presented compared to when the distractor is absent (McPeek, Skavenski, & Nakayama, 2000; Walker, Deubel, Schneider, & Findlay, 1997). Furthermore, eye movements are erroneously executed to the distractor in a proportion of trials (McPeek et al., 2000; Theeuwes, Kramer, Hahn, & Irwin, 1998). These effects are associated with the strong saccadic competition evoked by the irrelevant distractor.

It is important to note that the difference between this paradigm and the bilateral target presentation as used by Walker and Findlay (1996) is not trivial. The crucial difference is the presence of an element that has to be ignored in order to execute the task successfully. In the bilateral target paradigm, it is not an error to ignore one of the two presented elements, because the decision which element to fixate is undetermined. In the oculomotor distractor paradigm, the decision is based on the task demands. For instance, this setup enables to examine whether a patient with unilateral neglect is able to suppress an eye movement to a distractor presented in the ipsilesional field when the target is presented in the contralesional visual field. This way, a possible imbalance in the saccadic system can be revealed.

A single patient (LZ) with chronic left hemispatial neglect and a group of healthy participants performed the oculomotor distractor paradigm. In the experimental set-up, there were four possible target locations with one location in each quadrant of the visual field. In half of the trials, an irrelevant distractor was presented at one of the remaining three locations not occupied by the target. A number of experimental conditions are of interest; first, in the experimental condition in which only the target is presented, it will be investigated whether LZ is able to detect the target in the contralesional side. Furthermore, if an imbalance is indeed present in the saccadic system, it is expected that saccade latencies to the contralesional side will be longer compared to the ipsilesional side. In the experimental condition in which the distractor is presented, it will be investigated whether the distractor interferes with the correct selection of the target. This distractor interference will be reflected by an increase in saccade latency compared to when the distractor is absent and the percentage erroneous saccades executed to the distractor (i.e. oculomotor capture). However, when the distractor is presented in the contralesional field and the target in the ipsilesional field, no interference of the distractor is expected, because activity in the contralesional field is permanently suppressed. Finally, when the target is presented in the suppressed contralesional field and the distractor in the ipsilesional field, very strong distractor interference is expected.

2. Methods

2.1. Case report

LZ is a 66-year old right handed female, who suffered an acute subarachnoid haemorrhage (SAH) in 2000. After successful clipping of the ruptured aneurysm, severe vasospasms developed, resulting in a large ischemic infarction of the right hemisphere. Although the calcarine cortex was spared, the stroke affected the territories of both the middle and anterior cerebral artery including lateral occipital and temporal cortex, inferior and superior parietal lobules, the frontal and supplementary eye fields and the dorsolateral prefrontal cortex.

Early neuropsychological testing had revealed perceptual impairment (visual perception and construction), left-sided neglect, left-sided hemiparesis, but no memory or language deficits. Additionally, in 2005, she suffered a subdural haematoma (SDH) in the left hemisphere, resulting in language problems, which disappeared following the placement of a subdural drain to allow evacuation of the SDH via a burr hole (see Fig. 1 for a CT scan (2005)).

By the time of testing, she still showed moderate hemispatial neglect on standard neuropsychological tests (see Table 1). Additionally, on the visual confrontation test (i.e. reporting which of two fingers was moving (left, right, or both) while fixating the nose of the neuropsychologist), she missed all left-sided stimuli on both single and simultaneous trials, favoring hemispatial neglect over visual extinction. Official perimetry was also performed. LZ missed most of the stimuli presented left of the midline for both eyes. Moreover, she showed above average language and memory functioning (see Table 1).

2.2. Control participants

Six healthy participants were included (three males). The mean age was 58.8 years (st. dev. = 3.8 years). All participants had normal or corrected to normal acuity and no history of neurological or psychiatric deficits.

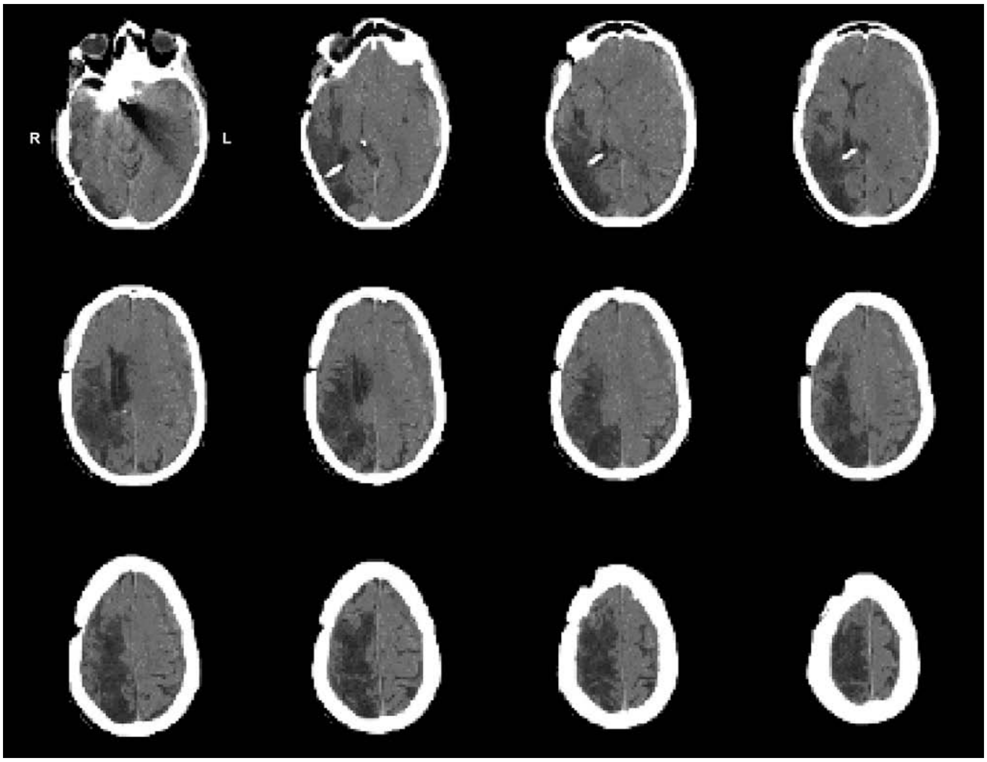

Fig. 1. CT scan (2005) showing the clip and the large infarction of the right hemisphere and the SDH in the left hemisphere.

Table 1
Performance of LZ on standard neuropsychological tests (70 months post-stroke).

Cognitive domain	Neuropsychological task	Performance	Percentile/decile
Language	Boston naming test	162	34th percentile[a]
Memory	Rey auditory verbal immediate recall	8/9/10/9/13	10th decile
	Delayed recall	11/15	7th decile
	Recognition	28/30	10th decile
Attention[b] (BIT)	Line bisection	3/9	
	Star cancellation	47/54	
	Letter cancellation	35/40	
	Line cancellation	30/36	
	Representation drawing	2/3	
	Figure and shape copying	1/4	

[a] Based on Dutch norms as described by van Loon-Vervoorn and Stumpel (1994).
[b] Standard neuropsychological tests for neglect; BIT: behavioral inattention test.

2.3. Apparatus

Eye movements were registered with the Eyelink2 system (SR Research Ltd, Canada), which has a 500 Hz temporal resolution and a spatial resolution of 0.025°, and uses an infrared video-based tracking technology to compute the pupil center and pupil size of the eyes. An infrared head mounting tracking system tracked head motion. The left eye was recorded and analyzed in all participants. The participants' heads were stabilized using a chin rest to control for compensatory head movements. The distance between monitor and chin rest was 65 cm.

2.4. Stimuli

See Fig. 2 for an illustration of the display sequence. All stimuli were presented in light gray (CIE xyY chromaticity coordinates of .280, .306, 3.86) on a black background (CIE xyY chromaticity coordinates of .422, .383, .04). Each trial started with the presentation of a central fixation cross (1.15° × 1.15°) which was present throughout the trial. After 800 ms the target (a light gray dot with a diameter of 1.15°) appeared. The dot was presented on an imaginary circle with radius of 9.62° centered

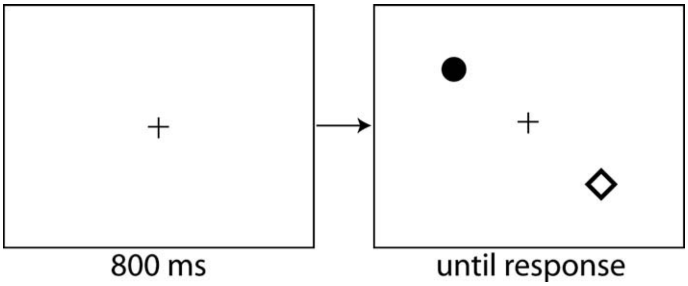

Fig. 2. Example of the display sequence (not drawn to scale). The trial started with the presentation of a central fixation cross. The target was a filled circle and the distractor an unfilled diamond.

on the fixation point. There were four possible target locations: 45° (i.e. upper right), 135° (i.e. lower right), 225° (i.e. lower left), or 315° (i.e. upper left) at this imaginary circle (the top of the circle being 0°). Simultaneously with the target onset, a gray diamond distractor (1.35° × 1.35°) appeared in half of the trials. When present, the distractor was always positioned at one of the other three locations. The target appeared with equal probability at each of the four locations and the distractor was presented with equal probability at one of the three remaining locations. Target and distractor remained visible until response.

2.5. Procedure and design

The participants performed the experiment in a dimly lit room. The participants were instructed to fixate the central cross until target onset and to subsequently make a single eye movement to the target location. Each block consisted of 216 trials. For LZ, four blocks were run during two sessions (2 months intervened between the two sessions). For the healthy participants, two blocks were run during one session. For all participants, the first 24 trials of the first block were considered training trials and not analyzed. Per block, trials with and without a distractor were equally distributed.

Each session started with a nine-point grid calibration procedure. The participant was required to saccade towards nine fixation points sequentially appearing at random in a 3 × 3 grid. In addition, simultaneously fixating the center fixation cross and pressing the space bar recalibrated the system at the start of each trial (i.e. drift correction).

2.6. Data analysis

Saccade latencies shorter than 80 ms and longer than 800 ms were removed and additionally, all latencies further than two standard deviations away from the mean latency per target location were also removed from the analysis. Moreover, trials were excluded from analysis when a saccade with an amplitude larger than 4° was made *before* target onset. When the target was present, the first saccade with an amplitude larger than 2° was considered the eye movement of interest. If the endpoint of this first saccade had an angular deviation of less than 40° from the center of the target or the distractor (for a more detailed explanation of the angular deviation restrictions, see Appendix A), the saccade was classified as landed on the target or the distractor, respectively. In other situations, the eye movement was considered an error and the trial was not further analyzed.

First, to investigate possible differences in percentage capture between the four different target–distractor configurations (i.e. target left, distractor left; target left, distractor right; target right, distractor left; and target right, distractor right), an ANOVA was performed for the healthy participants. Furthermore, to compare the percentage capture of LZ in these four target–distractor configurations to the results of the healthy participants, the Crawford and Howell's significance test on differences between individual's score and control sample was used (Crawford & Howell, 1998).

Second, for saccade latency, only the trials in which the first eye movement was correctly initiated to the target location were taken into account. Saccade latencies were analyzed using paired *t*-tests, for both LZ and the healthy participants separately. For the no-distractor condition, a possible difference in the latencies of saccades to targets in the left and in the right visual field was investigated. Furthermore, the latencies to targets in upper and lower quadrants were compared for both the left and right visual field. For trials in which the distractor was present, it was analyzed whether latencies were different compared to when the distractor was absent. This was done for each of the four different target–distractor configurations. Crawford and Howell's significance test on differences between individual's score and control sample was used to compare the saccade latencies of LZ to the results of the healthy participants (Crawford & Howell, 1998).

3. Results

3.1. Excluded trials

On the basis of the above-mentioned requirements, 16.9% of trials were excluded from the analysis for LZ (see below). For the healthy participants, a total of 9.4% of trials were excluded from the analysis.

3.2. Target detection in the no-distractor condition (LZ)

76.7% of the trials were included for targets in the left visual field, whereas 86.7% of the trials were included for targets in the right visual field. In Appendix A, a more detailed analysis of saccade accuracy for LZ is presented. The finding that for the left visual field, 70% of the eye movements ended with an angular deviation of less than 22.5° from the centre of the target, our regular criterion in a non-patient population (e.g., Van der Stigchel & Theeuwes, 2008), indicates that LZ was able to detect the target in her contralesional visual field and to execute a saccade to the left visual field to a single target, despite her visual neglect of the left visual field. Moreover, it indicates that LZ was not guessing when a target was presented in her contralesional visual field; she was able to make an accurate eye movement to an element presented in the contralesional visual field. Because the possible target and distractor locations were the same, this also holds that LZ was able to detect a distractor when presented in her contralesional visual field.

3.3. Percentage capture in the distractor condition

When a distractor was present, LZ as well as the healthy participants initiated a considerable number of eye movements to the distractor location ('capture'). For the healthy participants, no differences in the percentage capture between the four possible target–distractor configurations were observed (see Table 2; $F(3, 15) = 2.12$; $p > .10$). The mean percentage of capture in the healthy participants was 19.6% (st. dev. = 3.3%).

3.4. Target in right visual field

For LZ, when the target was positioned in the right visual field, eye movements were erroneously initiated to the distractor when presented in the *same* visual field as the target on 32.8% of the trials. This was significantly higher than the healthy participants ($t(5) = 3.70$; $p < .02$; estimated percentage of normal population falling below individual's score: 99.3%), which shows that LZ has an increased percentage of capture in her right visual field (see Fig. 3). However, when the *distractor* was presented in the *left* visual field and the target in the right visual field, this only occurred on 0.9% of the trials, which was significantly lower than the healthy participants ($t(5) = -5.25$; $p < .01$; estimated percentage of normal population falling below individual's score: 0.17%), indicating that LZ has no capture for left-side distractors when the target is presented in the right visual field.

3.5. Target in left visual field

When the target was located in the left visual field, a distractor in the *same* left visual field evoked an erroneous eye movement on 46.9% of the trials. This percentage was significantly higher than the healthy participants ($t(5) = 7.66$; $p < .01$; estimated percentage of normal population falling below individual's score: 99.97%). The experimental condition in which a *distractor* was positioned in the *right* visual field and the target in the left visual field showed a very high percentage of erroneous eye movements, namely 92.2%. This was again higher than the healthy participants ($t(5) = 20.37$; $p < .001$; estimated percentage of normal population falling below individual's score: 100%), indicating that LZ was captured more by right-side distractors when a target was presented in the left visual field.

In sum, when the target was presented in the right visual field, LZ was strongly captured by a distractor in the same visual field, whereas no capture was observed when a distractor was presented in the left visual field. However, when the target was presented in the left visual field, LZ's performance was around chance level when the distractor was presented in the same visual field. When the distractor was presented in her right visual field, LZ was almost always captured by this distractor.

3.6. Saccade latency in the no-distractor condition

It was investigated whether there was a difference between saccade latencies to targets in the left and right visual field in the no-distractor condition. For LZ, in line with the typical findings in left field visual neglect, saccade latencies to targets in the left visual field were longer than latencies to targets located in the right visual field ($t(160) = 14.02$; $p < .001$). There was no such effect in the healthy participants (see Fig. 4; $t(5) = 1.21$; $p > .20$).

Table 2
Overview of the percentage capture for the healthy participants, split on the different experimental conditions.

Target location	Distractor location	Percentage capture (st. dev., %)
Right	Right	25.5 (7.0)
Right	Left	14.8 (8.1)
Left	Right	24.1 (8.6)
Left	Left	26.0 (10.9)

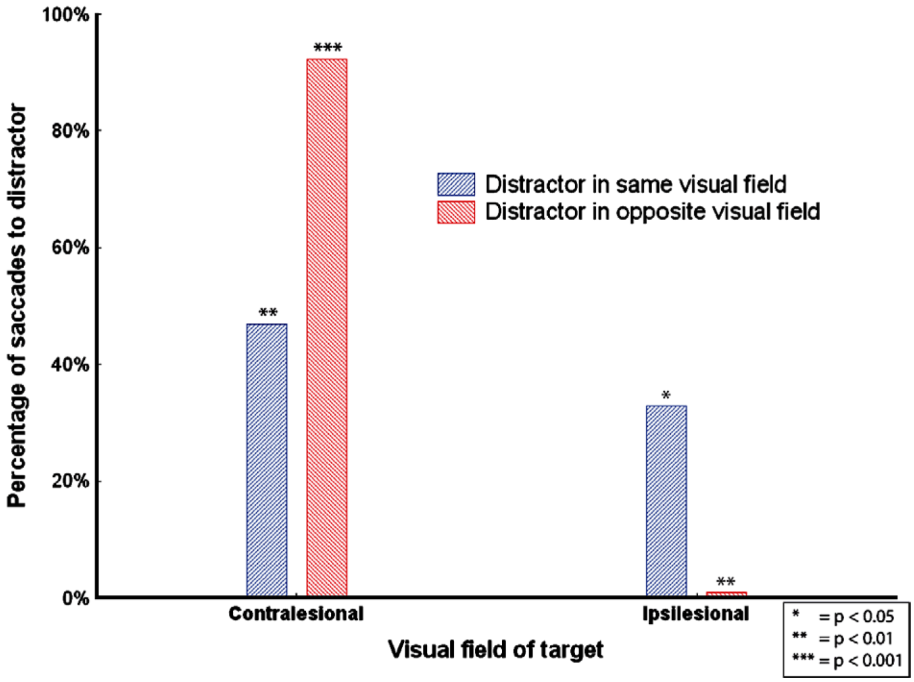

Fig. 3. Percentage of capture for LZ when the distractor was presented in the same or opposite visual field as the target. Significance level with respect to the healthy participants is displayed. Errors bars represent SEM.

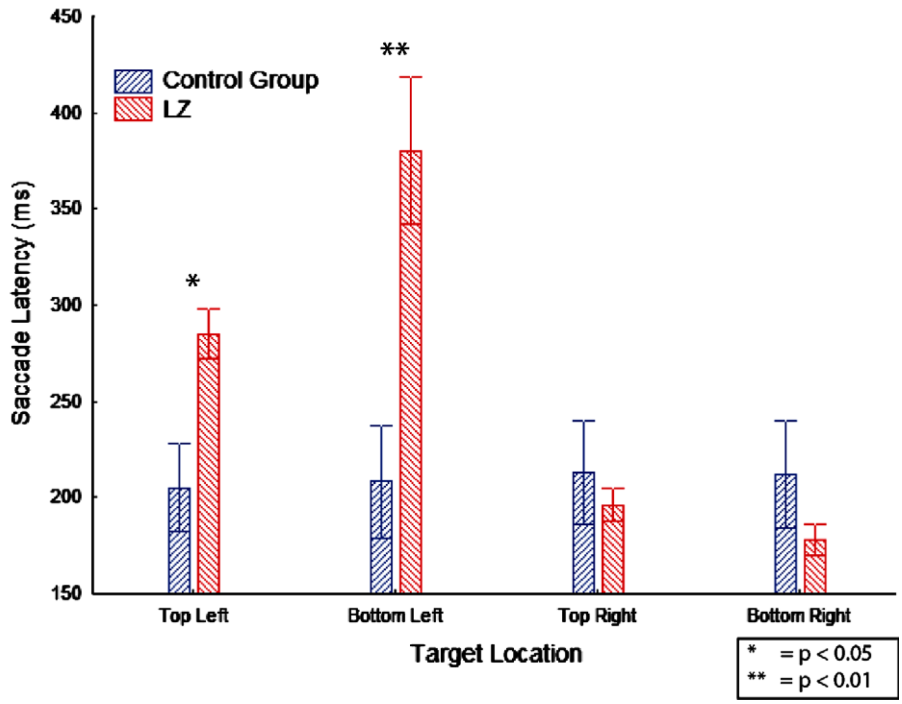

Fig. 4. Mean saccade latencies to the four possible target locations on distractor–absent trials. Errors bars represent SEM.

When comparing the performance of LZ to that of the healthy participants, it was found that latencies to the left side were longer for LZ compared to healthy participants ($t(5) = 4.39$; $p < 0.01$; estimated percentage of normal population falling below individual's score: 99.64%), whereas there was no difference in latencies to the right side between the healthy participants and LZ ($t(5) = -0.77$; $p > .40$; estimated percentage of normal population falling below individual's score: 23.86%). This shows that LZ was not overall slower compared to healthy participants in all experimental conditions.

Furthermore, saccade latencies differed for LZ in both left and right visual field with respect to the upper and lower target location (see Fig. 4). In the left visual field, upper visual targets showed shorter saccade latencies than lower visual targets ($t(69) = -4.55$, $p < .001$). However, in the right visual field, upper visual targets showed longer saccade latencies than lower visual targets ($t(89) = 3.32$, $p < .001$). Both these effects were absent in the healthy participants ($t(5) = 0.08$; $p > .90$; $t(5) = 0.45$; $p > .60$, respectively). Because latency differences between LZ's upper and lower visual field were also observed in her ipsilesional visual field, this effect is unlikely to be due to her visual neglect.

When a single target was presented in either the upper or lower left visual field, latencies were higher for LZ compared to the healthy participants (both comparisons: $t(5) \geqslant 3.03$; $p < .05$; estimated percentage of normal population falling below individual's score: $\geqslant$98.54%). Latencies to targets in the right visual field were not different for LZ and the healthy participants for both the upper and lower field (both comparisons: $t(5) \leqslant -0.51$; $p > .20$; estimated percentage of normal population falling below individual's score: 31.54%).

3.7. Saccade latency in the distractor condition

When a distractor was present, it could appear either on the same side as the target or on the other side. In trials in which the target was presented on the left side and the distractor on the right side, LZ made almost no correct eye movements to the target (see Section 3.3). Therefore, we only statistically analyzed the effect of the distractor when the target was presented in the right visual field.

In Fig. 5, mean latencies are shown for the experimental conditions in which the target was presented in the right visual field. For LZ, when the distractor was presented in the right visual field (similar to the target), saccade latencies were higher than in the no-distractor condition ($t(40) = 4.04$, $p < .001$). This effect was also present in the healthy participants ($t(5) = 0.59$; $p < .05$). When comparing the performance of LZ to that of the healthy participants, there was no difference between the latencies when the distractor was presented in the same right visual field as the target ($t(5) = -0.66$; $p > .50$; estimated percentage of normal population falling below individual's score: 27.09%) indicating that LZ was as fast as healthy participants in this experimental condition.

When the distractor was presented in the left visual field and the target in the right visual field, no effect of the distractor was observed for LZ compared to the no-distractor condition ($t(112) = -0.89$, $p = .376$). As expected, the distractor effect was present in the healthy participants ($t(5) = 5.66$; $p < .01$). When comparing LZ with the healthy participants, LZ was marginally

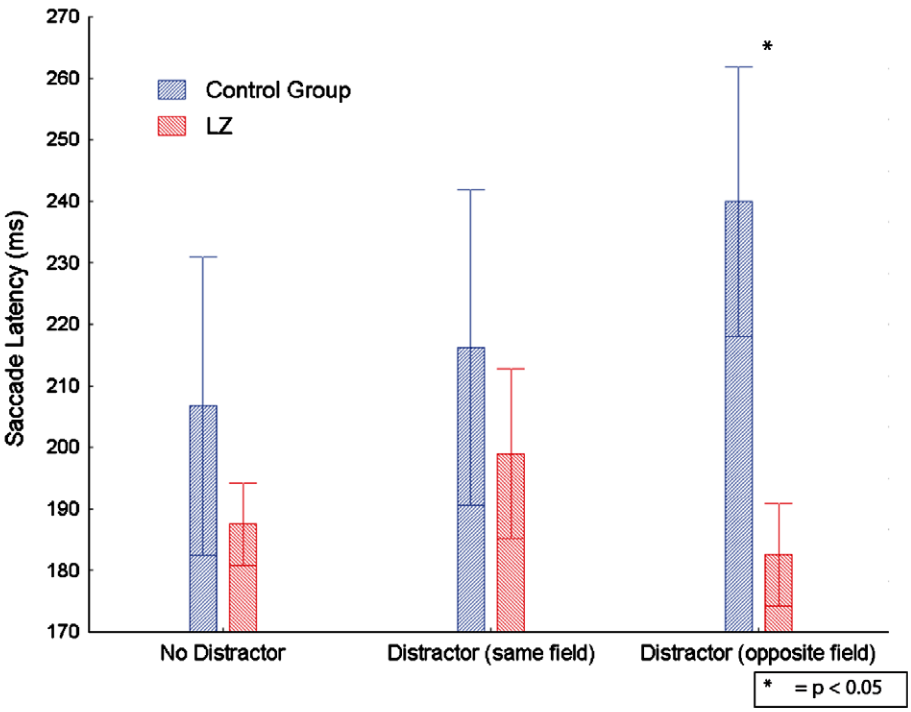

Fig. 5. Mean saccade latencies in the distractor and no-distractor conditions for targets presented in the right visual field only. Due to the high percentage capture for LZ when the distractor was presented in the left visual field, no mean saccade latencies could be shown for these conditions. Errors bars represent SEM.

faster than the healthy participants when the distractor was presented in the left field and the target in the right visual field ($t(5) = -2.54$; $p = .05$; estimated percentage of normal population falling below individual's score: 2.59%).

4. Discussion

The current study reports results of a patient with chronic hemispatial neglect (LZ) on an oculomotor distractor task. When the target was presented in her ipsilesional visual field, a distractor in the contralesional visual field evoked no oculomotor competition (no erroneous saccades to the distractor and no increase of saccade latency). However, when the target was presented in the contralesional visual field and the distractor in the ipsilesional visual field, LZ was almost always captured by the distractor. In this experimental condition, she executed many erroneous saccades to the distractor.

To investigate whether these findings are specific to hemispatial neglect, we tested two hemianopic patients for three blocks on the same experiment. Two conditions are of interest. First, in the no-distractor condition, it could be investigated whether the hemianopic patients are able to execute an eye movement to a contralesional target. As discussed above, LZ executed accurate eye movements to a single target in her contralesional visual field. If hemianopic patients are unable to accurately make a saccade to a contralesional target, this excludes the possibility that LZ has (additional) visual field defects for the target locations used in this study. Second, in the condition in which a target is presented in the contralesional visual field and a distractor in the ipsilesional visual field, it can be investigated whether the extreme capture is characteristic for neglect or whether this is also observed in hemianopia.

5. Control experiment

5.1. Case reports

Both cases had homonymous hemifield defects from lesions of the optic radiations or striate cortex due to strokes or intracerebral hemorrhages. These participants had lesions that affect the retinogeniculostriate pathway but not the retinotectal one (see Fig. 6). Both had complete blindness in the left part of the visual field as determined by perimetry. Case 1 was a 53-year old male who had a small partial infarct of the posterior occipital lobe 38 months before testing. Case 2 was a 56-year old male who had a more extensive infarct in the territory of the posterior cerebral artery 62 months before testing, affecting medial occipital and temporal structures, including the lingual gyrus and parahippocampal cortex.

6. Results and discussion

6.1. No-distractor condition

Both patients were unable to saccade to a target in the contralesional visual field; correct performance for contralesional targets was around 2.0%, because both patients did not detect the target (i.e. they made no eye movement to the contralateral field in most of the trials). In contrast, LZ was able to accurately execute an eye movement to a contralesional target in 76.7% of the trials.

6.2. Distractor condition

When the target was presented in the contralesional visual field and the distractor in the ipsilesional visual field, the hemianopic patients showed on average percentage capture of 33.0% (st. dev. = 15.6%) in this experimental condition, in contrast to 92.2% for LZ. The remaining trials were errors. This shows that the extreme capture by an ipsilesional distractor is specific to hemispatial neglect.

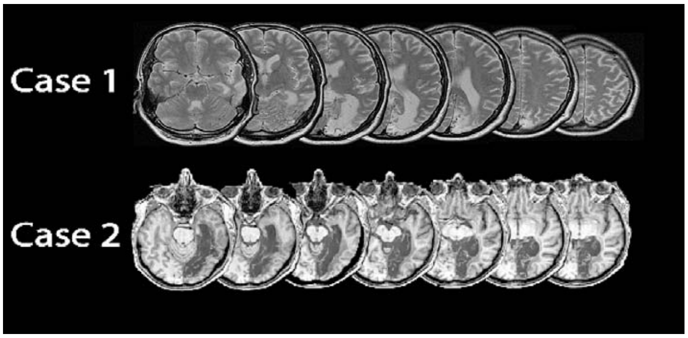

Fig. 6. Axial MRI or CT images of the lesions of the hemianopic cases.

When the target was presented in the ipsilesional visual field and the distractor in the contralesional visual field, the hemianopic patients initiated no erroneous eye movements to the distractor location (0.0%). This is similar to the results of LZ.

7. General discussion

The current study investigated the effect of an irrelevant distractor on eye movement behavior in a patient with chronic hemispatial neglect (LZ). The target element could appear in one of the four quadrants of the visual field and was accompanied by a distractor in half of the trials. Note that the distractor was never presented in the same quadrant as the target. Results showed that LZ was able to execute an eye movement to all target locations when the target was presented alone. Compared to healthy participants, LZ showed longer saccade latencies for eye movements to the left visual field. These results are in line with previous findings that neglect patients are able to execute eye movements to the contralesional side, albeit with longer latencies (e.g., Behrmann, Ghisella-Crippa, & Dimatteo, 2001/2002; Girotti, Casazza, Musicco, & Avanzini, 1983; Harvey, Olk, Muir, & Gilchrist, 2002).

Furthermore, it was found that when the distractor was presented simultaneously with the target, saccade latencies increased when both elements were presented in the ipsilesional visual field. This interfering effect of the distractor is in line with previous findings in non-clinical populations (Godijn & Theeuwes, 2002; Walker et al., 1997). When the distractor was presented in the contralesional visual field, however, saccade latencies to a target in the ipsilesional field were not influenced in LZ, indicating that the distractor did not evoke interference. This finding was also reflected in the percentage of erroneous saccades (i.e. capture) as there were almost no eye movements initiated to a contralesional distractor when the target was presented in the ipsilesional field. However, when both elements were presented in the ipsilesional field, an abnormally high number of saccades were erroneously initiated to the distractor (i.e. competition by the distractor was too strong) (Godijn & Theeuwes, 2002; Theeuwes et al., 1998). The highest percentage of capture was observed in the experimental condition in which the target was presented in the contralesional field and the distractor in the ipsilesional field. In this experimental condition; almost no eye movements were correctly initiated to the target.

These results are in line with the hypothesis that visual neglect is associated with an imbalance in the saccadic system. The contralesional visual field is permanently suppressed which makes it unlikely for elements in that part of the visual field to win the competition for saccadic selection (Walker & Findlay, 1996). A distractor in the contralesional (i.e. 'suppressed') visual field did not influence the saccade to the target, which shows that the activity of the distractor summed with the activity of the contralesional field did not pass the threshold for saccadic competition.

Results also showed that a distractor in the ipsilesional field evoked very strong competition when the target was presented in the contralesional field. Moreover, the interference of the distractor was so strong in almost all these trials that LZ was unable to suppress an eye movement to the distractor location. When it is assumed that the activity in the contralesional field is suppressed because of the imbalance in the oculomotor system, this will result in a 'hyperattraction' to elements presented in the ipsilesional visual field: the highest activity in the visual field will be located in the ipsilesional field, which makes it likely for ipsilesional distractors to win the competition. Indeed, there is considerable evidence that activity in the ipsilesional visual field in unilateral neglect is particularly strong (i.e., Làdavas, 1990; Làdavas, Petronio, & Umilta, 1990). For instance, influential vector models of visual neglect assume that the rightward attentional bias is unopposed by a leftward bias which normally balances the activity in both visual fields (Kinsbourne, 1970, 1993). The lack of a leftward bias due to the parietal lesion directs attention to the ipsilesional side. Although in the current study LZ did not show faster saccades to ipsilesional targets compared to healthy participants (as shown by, Harvey et al., 2002), hyperattraction of ipsilesional elements might account for the high percentage of capture when the distractor was located in the ipsilesional and the target in the contralesional field. Also, the finding that LZ was faster than controls to initiate a saccade to an ipsilesional target when the distractor appeared in the contralesional visual field is line with this idea. The hyperattraction might also explain the higher percentage of capture when *both* target and distractor were presented in the *ipsilesional* field; the higher activity in the ipsilesional field increased the likelihood of responses based on bottom–up information. If neglect patients respond more strongly to bottom–up information in the ipsilesional visual field, the distractor wins the competition more frequently on the basis of visual, bottom–up, information than in the control group. This ipsilesional deficit is in line with results of previous attention tasks in neglect patients, in which ipsilesional target detection was decreased when an ipsilesional distractor was presented (e.g., Vuilleumier & Rafal, 2000). The current findings show that this ipsilesional attentional deficit extends to the oculomotor domain.

It might appear trivial that contralesional distractors did not interfere with target selection, because there were presented in a neglected visual field. However, previous studies have revealed that a distractor can interfere with target selection, even in the absence of awareness of the distractor. This has not only been shown in healthy observers (Mulckhuyse, Talsma, & Theeuwes, 2007; Van der Stigchel, Mulckhuyse, & Theeuwes, 2009), but also in patients with neglect (e.g. Làdavas, Zeloni, Zaccara, & Gangemi, 1997). Làdavas et al. (1997), for instance, found that some neglect patients made saccades to contralesional targets which they failed to report. This was only observed for patients with fronto-parietal lesions and not for patients with parietal lesions. Because LZ has lesions involving frontal and parietal regions, the absence of an interfering effect of a contralesional distractor is inconsistent with the findings of Làdavas et al. (1997). This discrepancy might be explained by the extensive lesions of LZ which included all regions of the oculomotor cortex, including the dorsolateral prefrontal cortex and supplementary eye fields.

One could argue that the obtained results are due to (an additional) hemianopia, because visual neglect and hemianopia are sometimes difficult to disentangle (Walker, Findlay, Young, & Welch, 1991). For instance, perimetry cannot distinguish between visual neglect and hemianopia, because a patient with visual neglect could show the same pattern of performance on perimetry as a hemianopic patient (especially with stimuli that are presented for only 100 ms) (Vallar, Sandroni, Rusconi, & Barbieri, 1991). To exclude the possibility that the obtained results could be explained by hemianopia, we tested two hemianopic patients on the same experiment. Results showed that both patients were unable to saccade to a target in the contralesional visual field. In contrast, LZ was able to accurately execute an eye movement to a contralesional target (see also Appendix A). This shows that LZ does not have any field defects, at least at the locations where stimuli would be presented during the experiment. LZ was not 'guessing' when there was no target presented in the ipsilesional visual field or simply executing a left-directed saccade whenever she did not see anything in the ipsilesional visual field. Furthermore, the extreme capture by a distractor in her ipsilesional field with a contralesional target is unexpected on the basis of a visual field defect. Indeed the hemianopic patients showed a lower percentage capture in this condition than LZ.

The current findings are reminiscent of a recent study who reported the results of an oculomotor distractor paradigm from a patient with a unilateral parietal lesion. This study also showed that a distractor in the contralesional field interfered less when a target was presented in the ipsilesional field (Butler, Gilchrist, Ludwig, Muir, & Harvey, 2006). However, this patient did not show any signs of neglect. The authors explained this result in terms of an extinction-like pattern (i.e. an impairment in identifying one stimulus during simultaneous presentation of multiple stimuli). Importantly, in the 2006 study, the contralesional distractor still evoked a considerable percentage of capture (17%), whereas in the current study the percentage of capture in this experimental condition was only 1%. Our results are not likely to be influenced by the presence of pure visual extinction, because eye movements to the contralesional field were associated with longer latencies in the no-distractor condition than eye movements to the ipsilesional field. This does not fit with a pattern in which visual extinction is solely responsible for the obtained results, as saccade latencies to the contralesional field should have been the same as latencies to the ipsilesional field (Schendel & Robertson, 2002).

As mentioned in the introduction, 'oculomotor capture' is defined as an erroneous eye movement executed to the distractor (see also, Van der Stigchel, in press). In contrast to the original oculomotor capture paradigm as designed by Theeuwes et al. (1998), the distractor in our study is not more salient than the target. One might therefore question whether the erroneous eye movements to the distractor are driven by bottom–up signals. We would like to argue that eye movements executed to the target are, by definition, driven more strongly by top–down signals than eye movements executed to the distractor. An eye movement to a distractor reflects a lack of top–down control and corresponds to an eye movement which is dominantly executed on the basis of bottom–up visual information. In line with this, saccade latencies of correct saccades to the target when a distractor was present are longer than erroneous saccades to the distractor (control participants: $t(5) = 5.77$; $p < .002$). This strengthens the idea that errors are driven more strongly by bottom–up signals than correct saccades.

As visual neglect is generally associated with an attentional deficit (Kinsbourne, 1987), the question arises what the current results learn us about the attentional deficits in neglect. As there is a strong overlap between the mechanisms responsible for programming eye movements and allocating visual attention (Rizzolatti, Riggio, & Sheliga, 1994; Van der Stigchel & Theeuwes, 2005), any deficits observed within the oculomotor domain are likely to be related to deficits within the attentional domain. Indeed, the strong version of the premotor theory of attention states that shifts of attention are a by-product of the preparation of an eye movement to a particular location in space (Rizzolatti et al., 1994; Sheliga, Riggio, & Rizzolatti, 1994). It is interesting that both views of attentional deficits in neglect are consistent with the current results. One the one hand, the view that neglect is associated with an inability to direct attention to the contralesional hemifield (Kinsbourne, 1987) is supported by the finding that saccade latency to single contralesional distractors was longer than for controls. One the other hand, the view that extreme capture of information in the ipsilesional hemifield is the root of the behavioural deficits in neglect (Marshall & Halligan, 1989) is consistent with the findings that the distractor in the ipsilesional visual field evoked an abnormally high number of erroneous saccades.

This is the first study measuring eye movements in response to a single task-irrelevant distractor in hemispatial neglect. It revealed that a contralesional distractor did not influence saccadic eye movements and did not introduce oculomotor capture for eye movements to the intact visual field. Furthermore, it showed that eye movements are extremely captured by an ipsilesional distractor. The current study provided further evidence for an imbalance in oculomotor activity in visual neglect.

Acknowledgements

The authors would like to thank LZ and her husband for participation, great humor and the great support of our research. We thank Robert Rafal for his useful suggestions.

Appendix A. Determining saccade endpoint

If the endpoint of this first saccade had an angular deviation of less than 40° (i.e. minute of arc) from the centre of the target or the distractor, the saccade was classified as landed on the target or the distractor, respectively. See Fig. A1 for an illustration of the angular deviation.

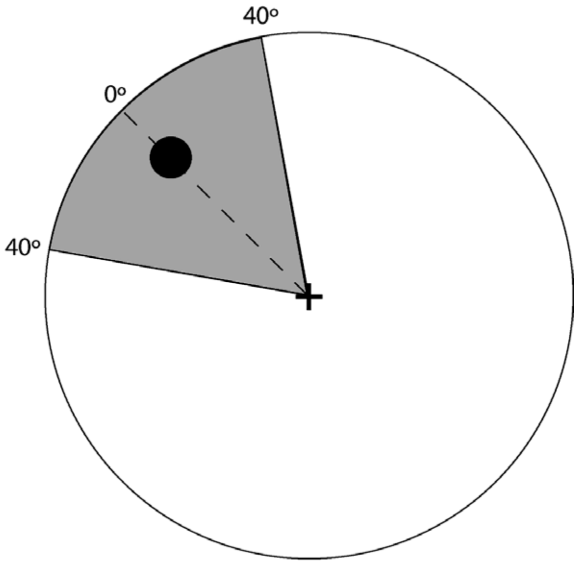

Fig. A1. Illustration of the classification of saccade endpoint. The filled circle represents either the target or the distractor.

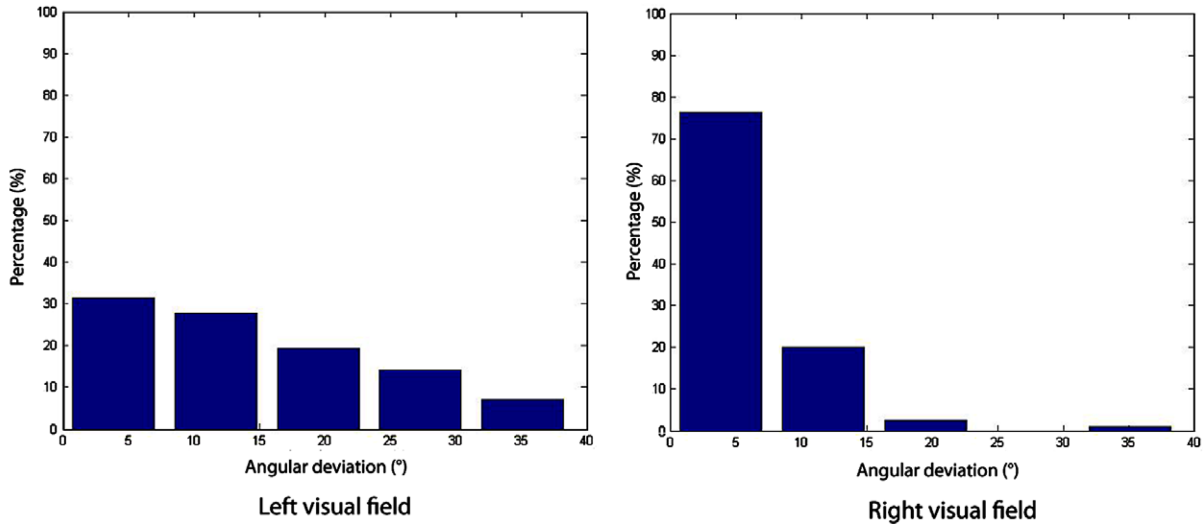

Fig. A2. Distribution of saccades for LZ to a target in the left and right visual field in the no-distractor condition.

Although one could argue that this is a liberal criterium, we believe there are good reasons for using this criterium. First, and most importantly, eye movements that are captured by a distractor are less accurate than eye movements that are initiated to the target (Theeuwes et al., 1998). These automatic eye movements are characterized by a smaller amplitude and a more 'rough' endpoint (i.e. more remote from the distractor location). Second, we wanted to increase our statistical power by including those trials in which the endpoint was located in the relevant quadrant.

In Fig. A2, the distribution of saccades for LZ to a target in the no-distractor condition is displayed for both the left and right visual field. The angular deviation of the different saccades is binned into five equally spaced containers. These graphs verify our judgement that our recording was accurate. Even for the left visual field, 70% of the eye movements ended with an angular deviation of less than 22.5° from the centre of the target, our regular criterion in a non-patient population (e.g., Van der Stigchel & Theeuwes, 2008).

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