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Optokinetic stimulation affects word omissions but not stimulus-centered reading errors in paragraph reading in neglect dyslexia

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ABSTRACT

Patients with right hemisphere lesions often omit or misread words on the left side of a text or the initial letters of single words, a phenomenon termed neglect dyslexia (ND). Omissions of words on the contralesional side of the page are considered as egocentric or space-based errors, whereas misread words can be viewed as a type of stimulus-centered error where the left part of a single perceptual entity (the word) is neglected. Previous patient studies have shown that optokinetic stimulation (OKS) significantly modulates many facets of the neglect syndrome, including the subjective body midline, line bisection and size distortions. An open question is whether OKS can also influence omissions and stimulus-centered errors in *paragraph* reading in ND. The current study compared the influence of OKS on both types of reading errors using controlled indented paragraph reading tests in a group of 9 right-hemisphere lesioned patients with ND, 7 patients without ND and 9 matched healthy controls. Leftward OKS significantly reduced omissions on the left side of the text in ND. In contrast, the pattern of stimulus-centered reading errors remained unchanged. In conclusion egocentric manipulations like OKS only appear to influence space-based attentional processes evident as omissions in paragraph reading but have no impact on stimulus-centered attentional processes evident as word-based errors during paragraph reading in ND.

1. Introduction

Patients with right brain lesions often show a conspicuous syndrome where they do not report or respond to stimuli presented in the contralesional hemispace in the absence of any primary sensory or motor deficits, termed neglect. Several investigations found dissociable subtypes of neglect concerning different aspects of spatial processing. For instance, neglect symptoms can affect perception or action (Heilman, 2004; Heilman, Valenstein, & Watson, 2000), representational imagination (Bisiach & Luzzatti, 1978; Bisiach, Luzzatti, & Perani, 1979), near space and far space representation (Landis, 2000; Marshall & Halligan, 1995; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998) or reading (Vallar, Burani, & Arduino, 2010), to name only a few dissociations of the neglect-syndrome reported so far.

Importantly, visual neglect symptoms can occur in different spatial reference frames. Egocentric neglect phenomena concern the failure to attend to stimuli on the contralesional (left) side of the midsagittal plane of the body or certain body parts (Ventre & Flandrin, 1984). Typically, neglect patients show severe impairments in many egocentric tests of neglect that have been conducted so far (i.e. cancellation, visual and tactile exploration, writing, see for review Chokron, Dupierrix, Tabert, & Bartolomeo, 2007). Another component of neglect is termed allocentric neglect where the contralesional side of a single perceptual object is neglected irrespective of its location in space. Clinically, neglect patients often show impairments in tasks such as drawing a symmetrical figure or perceiving or copying a face (Halligan, Fink, Marshall, & Vallar, 2003). Here, in contrast to egocentric neglect phenomena, the patient's body (trunk, head, eyes, etc.) does not serve as a midline reference for the performance in these tasks, and therefore these impairments may occur with a similar frequency in both hemispaces. Several studies have shown that ego- and allocentric neglect phenomena are dissociable and rely on different neural structures. These studies are consistent with the hypothesis that egocentric visual information processing is linked primarily to parieto-frontal brain areas in the dorsal stream whereas allocentric, object-centered visual processing is linked more closely to ventral stream areas (Grimsen, Hildebrandt, & Fahle, 2008; Hillis et al., 2005; Honda, Wise, Weeks, Deiber, & Hallett, 1998; Vallar et al., 1999; Verdon, Schwartz, Lovblad, Hauert, & Vuilleumier, 2010).

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1.1. Neglect dyslexia (ND)

Even if visual left spatial neglect and ND are often associated, there is evidence that spatial neglect can occur without ND and vice versa (Vallar et al., 2010). Left-sided neglect can impair reading in different ways. Patients typically start reading in the middle of the text, reading to the end, and then jumping to the middle of the next text line. Other errors typically involve the left side of words where initial letters are omitted or substituted by other letters. These substitutions or omissions of letters mostly lead to reading errors producing alternative, words but not neologisms (e.g. misreading “start” as “art” or “mouse” as “house”, cf Ellis, Flude, & Young, 1987; Kinsbourne & Warrington, 1962). However, as the meaning of the misread word does not resemble the original word, ND leads to a deficit in comprehension. Interestingly, patients usually are not aware of misreading words (Kinsbourne & Warrington, 1962).

Based on the assumption that words are a class of perceptual objects (for a theoretical discussion see Monk, 1985) Caramazza and Hillis (1990a) adapted Marr and Nishiharas’ (Marr, 2010; Marr & Nishihara, 1978) levels of processing model for the early stages of visual word recognition. According to Caramazza and Hillis’ model, words are processed at three representational levels from the visual features of the word to an abstract description of the letter. The first level of representation is characterized by a retinocentric parallel analysis of discontinuities of the retinal reflection that defines the features of letters (like lines and dots). At the second level, a sequential analysis of different sub-parts of the feature map results in a stimulus-centered letter shape representation. Caramazza and Hillis postulate that a third level of representation (word-centered representation) must be processed before letter naming, lexical access or grapheme–phoneme conversion can occur. This third level contains a description of abstract graphemes and their relative spatial position in a word (Caramazza & Hillis, 1990a).

Deficits at the first level (egocentric representation) should depend on the location of the letter string relative to the patient’s point of fixation. In this case, patients should omit part of sentences or single words presented on the contralesional side with reference to the point of fixation. This type of ND has been observed for the left as well as for the right hemispace (Behrmann, Moscovitch, Black, & Mozer, 1990; Hillis & Caramazza, 1995; Riddoch, Humphreys, Cleton, & Fery, 1990; Subbiah & Caramazza, 2000; Vallar et al., 2010). In contrast, a disturbance of the stimulus-centered or word-centered level should cause misreadings of the left (in right-brain damaged patients) side of single words without affecting the number of errors depending on the location of a word in the visual field. Indeed, there is evidence for specific ND occurring on the second or the third levels of visual word processing (Behrmann et al., 1990; Ellis et al., 1987; Hillis & Caramazza, 1991, 1995; Riddoch et al., 1990; Siéroff, 1991; Subbiah & Caramazza, 2000; Young, Newcombe, & Ellis, 1991; for a review see Haywood & Coltheart, 2000).

The intensive research on *single* word reading in ND in the past two decades has provided many important insights into the mechanisms of single word reading (Ellis et al., 1987), spared and impaired levels of performance in ND (Làdavas, Umiltà, & Mapelli, 1997), the nature of object-centered “word-form” representations in the brain (Caramazza & Hillis, 1990b), the identification of viewing-position effects (Stenneken, van Eimeren, Keller, Jacobs, & Kerkhoff, 2008) as well as associations and dissociations with other forms of visuospatial neglect (Lee et al., 2009), to name only a few advancements in the field of research into word-identification mechanisms. In contrast, comparatively few studies investigated ND for *paragraph reading*. This is surprising given that paragraph or text reading subtests are often part of standard neglect screening batteries such as the Behavioural Inattention Test, (Halligan, Marshall, & Wade, 1989; Wilson, Cockburn, & Halligan, 1987) or the extensively validated French GEREN/GRECO neglect test battery (Azouvi et al., 2002). Studies using the “Indented paragraph reading test” (Bachman, Fein, Davenport, & Price, 1993; Caplan, 1987; Towle & Lincoln, 1991) all have shown its high diagnostic sensitivity for neglect, partially because the indented margin on the left side requires frequent refixations by the patient. However, these three studies mainly considered contralesional omissions but not stimulus-centered reading errors. In an oculographic study of ND Behrmann, Black, McKeeff, and Barton (2002) had their patients read single words distributed randomly on a visual display comparable to a visual search task. Apart from reporting task-dependent dissociations of ND and visuospatial neglect, they provided evidence that omitted (contralesional) words were often not fixated properly while ipsilesionally presented words showed a pattern of hyperfixation, hence were read correctly but refixated too often. This dysfunctional oculographic pattern of results may suggest a low-level visual impairment (i.e. eye-movement deficits) or impaired spatial working memory as potential sources of reading errors in ND.

In a recent study (Reinhart, Keller, & Kerkhoff, 2010) we investigated paragraph reading in right brain damaged patients with vs. without ND, under different egocentric manipulations induced by passive head rotation to the contralesional (neglected) or ipsilesional side. The bilaterally indented text reading task used in this study allowed us to investigate egocentric and word- centered ND *simultaneously*. Interestingly, leftward head rotation significantly reduced word omissions in ND but failed to influence stimulus-centered reading errors in the very same task and patients. During reading, the gaze is focused on single words and therefore the question arises why stimulus centered reading errors were not influenced by an egocentric manipulation like head rotation that significantly influenced the word omissions in ND.

In the present study we analysed the influence of another well-known egocentric manipulation, namely optokinetic stimulation (further termed OKS Kerkhoff, 2003) on omissions and stimulus-centered reading errors in right brain damaged patients with vs. without left-sided spatial neglect. Previous studies using OKS have shown significant modulatory effects in visual line bisection (Mattingley, Bradshaw, & Bradshaw, 1994; Pizzamiglio, Frasca, Guariglia, Incoccia, & Antonucci, 1990), the subjective visual straight ahead (Karnath, 1996), visual size distortions (Kerkhoff, 2000; Kerkhoff, Schindler, Keller, & Marquardt, 1999), visual distance judgements (Schindler & Kerkhoff, 2004), tactile extinction (Nico, 1999), motor deficits (Vallar, Guariglia, Nico, & Pizzamiglio, 1997), and even neglect of the mental number line in neglect (Salillas, Granà, Juncadella, Rico, & Semenza, 1999).

In the present study, we sought to investigate whether OKS has an effect on both types of reading errors (word omissions and stimulus-centered errors). Moreover, given that OKS has an effect on reading errors, does this manipulation influence both types of reading errors in a comparable way like head rotation? More generally, we asked, how could a potential effect of OKS contribute to the understanding of ego- and stimulus-centered mechanisms during paragraph reading?

2. Methods

2.1. Subjects

Nine patients with right-hemispheric, vascular brain lesions and moderate to severe left-sided visual neglect, according to the results of three conventional neglect screening tests (see below, Section 2.2), were included. Another group of seven patients with vascular, right brain damage showing no visual neglect in the same screening tests and with comparable clinical and demographic criteria was investigated. Nine healthy subjects without brain damage (6 males, 3 females, age range: 33–67, mean age 46 years) were recruited as controls. All subjects had a decimal visual acuity of at least 0.70 (20/30 Snellen equivalent) for the near

Table 1
Clinical and demographic data of 9 patients with left visual neglect after a single vascular lesion of the right hemisphere (A, subjects $N+1$ to $N+9$), and 7 patients with a single right hemispheric infarction without neglect (B, $N-1$ to $N-7$).

Subject	Visual neglect	Age, sex	Etiology	Months post lesion	Lesion location	Field defect, field sparing (°)	Figure copy left/right side	Clock drawing left/right side	Reading (% errors)
(A) Right brain damaged patients with left visual neglect									
$N+1$	Yes	55, f	ICB	9	Parietal	Left hemianopia, 5°	−/+	−/+	20
$N+2$	Yes	55, m	MCI	4	Thalamus, parietal	Normal	−/−	−/+	33
$N+3$	Yes	61, m	MCI	3	Temporal	Left hemianopia, 1°	−/+	−/+	10
$N+4$	Yes	55, f	MCI	3	Parietal, temporal	Left hemianopia, 5°	−/+	−/+	8
$N+5$	Yes	60, m	MCI	4	Parietal,	Left hemianopia, 30°	−/+	+/+	22
$N+6$	Yes	68, m	MCI	4	Parietal, temporal	Left hemianopia, 20°	−/+	−/+	25
$N+7$	Yes	39, m	MCI	5	Parietal, temporal	Normal	−/+	−/+	35
$N+8$	Yes	45, f	MCI	9	Frontal, temporal	Normal	−/+	−/+	11
$N+9$	Yes	50, m	MCI	2	Temporal	Normal	−/+	−/+	8
Mean		54.2		4.9 (2–9)		5/9 impaired	9 impaired	8 impaired	19.1%
Subject	Visual neglect	Age, sex	Etiology	Months post lesion	Lesion location	Field defect, field sparing (°)	Figure copy left/right side	Clock drawing left/right side	Reading (% errors)
(B) Right brain damaged patients without visual neglect									
$N-1$	No	29, f	MCI	1	Temporal	Normal	+/+	+/+	0
$N-2$	No	62, f	MCI	4	Frontal, parietal	Normal	+/+	+/+	1
$N-3$	No	44, m	MCI	6	Temporal	Normal	+/+	+/+	0
$N-4$	No	62, m	MCI	3	Temporal, basal ganglia	Left hemianopia, 5°	+/+	+/+	0
$N-5$	No	57, f	MCI	12	Parietal, occipital	Normal	+/+	+/+	1
$N-6$	No	50, f	MCI	4	Parietal, occipital	Left hemianopia, 20°	+/+	+/+	0
$N-7$	No	62, m	MCI	4	Temporal	Left hemianopia, 4°	+/+	+/+	1
Mean		52.2		4.8 (1–12)		3/7 impaired	0 impaired	0 impaired	0.1%

Abbreviatons: ICB, intracerebral bleeding; MCI, middle cerebral artery infarction; BG, basal ganglia; MCA/PCA, middle cerebral artery infarction; L/R, left/right; visual field: field sparing is indicated in (°) on the left horizontal meridian in the blind field. *Neglect screening tests:* Paragraph reading of a 180 word reading test: cutoff max 2 errors, figure copy: − = omissions or distortions; + = normal performance; cancellation: number of omissions on the left/right side of the page, normal cutoff: max 1 omission per side.

viewing distance (0.4 m) and were appropriately corrected during the experiment. All subjects had at least 9 years of education (see Table 1 for clinical and demographic details).

2.2. *Visual field and visual neglect assessment*

Kinetic monocular perimetry was performed in the majority of patients ($N = 12$) with a Tuebingen perimeter (Aulhorn & Harms, 1972) using a bright white stimulus (size: 106″, luminance: 102 cd/m^2), a grey stimulus (106″, 1.02 cd/m^2), a coloured target (green 525 nm, same size, 320 cd/m^2 and a form target (white light, same size, rhomboid, 320 cd/m^2). Kinetic perimetry was performed along all meridians in a pseudorandom order. Visual field sparing is indicated in Table 1 for the left horizontal meridian. In the remaining four patients kinetic Goldmann perimetry was performed monocularly with the largest test stimulus (V4) in the same way as described above. Visual neglect was tested with 3 conventional tests, most of them very similar to those of the Behavioural Inattention Test (Halligan et al., 1989; Wilson et al., 1987): clock drawing from memory, figure copy (star, flower, cube) and paragraph reading of a 180-word reading test (Kerkhoff, Münßinger, Eberle-Strauss, & Stögerer, 1992). All screening tests were shown on a 29.7 × 20 cm white paper board – perpendicular to the patient's trunk midline – and at a distance of 0.33 m from the patient's eyes.

2.3. *Experimental reading tests*

As indented paragraph reading tasks are a highly sensitive measure of reading in neglect (Bachman et al., 1993; Caplan, 1987; Towle & Lincoln, 1991) and are not confounded by differences in years of schooling (Bachman et al., 1993), we constructed 45 short reading texts (mean length: 51.7 words, range: 43–65; arranged in 8–10 lines) of different length from two story books. The margins of each text were irregularly indented on both sides in order to facilitate comparisons of errors on the left vs. right text side; see examples in Appendixes A and B). Eight to 10 words on every margin (left and right side) of each text were filler words (for example words as "a", "but", "in", very", often", etc.) and were not necessary for the semantic context of the text. The main message of the text can be understood even if most or all of these filler words are neglected. This served to increase the sensitivity of the paragraph reading tests for neglect. All texts were matched with respect to length (number of words, letters and lines), spatial arrangement and complexity as judged by the performance of the normal subjects. Each text was displayed sequentially one by one within an 8 × 12° large rectangular white field on a 17″-computer screen. Texts were presented in black print (Arial, point size 22) on a white background at a distance of 0.5 m to the patient's eyes. The number of words displayed on each side of the reading texts was balanced (mean length left: 25.8 words, mean length right: 26.00 words). There was no statistical difference between the number of words presented on the left and right text side when all 45 texts were compared ($t(88) = 0.34$, $p = 0.73$).

2.4. *Experimental conditions*

Four experimental conditions were used. (1) first baseline test; (2) optokinetic stimulation with leftward movement of the dots in the background (left OKS); (3) optokinetic stimulation with rightward movement of the dots in the background (right OKS); (4) second baseline test (Fig. 1). For optokinetic stimulation, computer-generated random displays of 100 yellow dots (3 cm in diameter) were shown on a black background, all moving coherently and horizontally towards the left, or right side, with a constant speed of 11.3°/s. The spatial extension of the total screen was 15° in the horizontal and 12° in the vertical dimension for each hemifield; the spatial extension of the inner window where the reading texts were displayed was 8° horizontally and 5° vertically for each hemifield. The moving dots surrounded the rectangular window in which the reading tests were successively shown, but did not move over the text display in order to avoid disturbances of the reading process itself (see Fig. 1 for details).

The two baseline conditions were performed at the beginning and very end of the experimental session to control for order effects. The sequence of the second and third experimental session was counter-balanced: half of all subjects received OKS to the left followed by OKS to the right, and vice versa. In all conditions the subject's head position was aligned with the centre of the screen which was controlled by a head-rest and monitored by the experimenter. The subjects were instructed to read out the complete text displayed on screen. Reading was tape-recorded for later

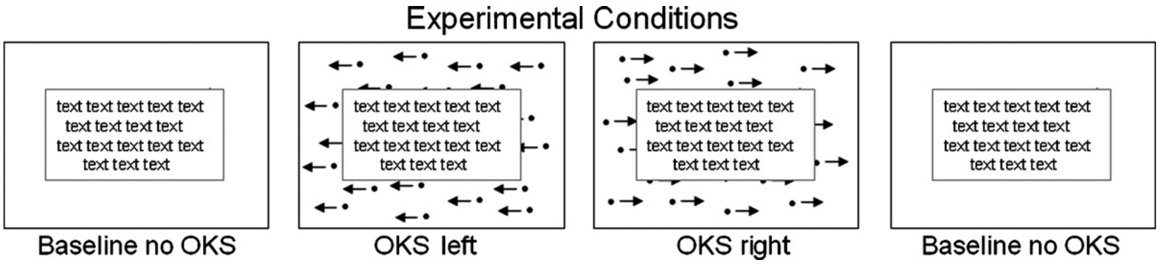

Fig. 1. Experimental conditions. The two baselines were given at the beginning and very end of the experiment. The sequence of the second and third experimental session was counter-balanced across subjects.

off-line analysis, and simultaneously scored on a paper printout of the same texts displayed on the monitor. Five reading texts were presented during each experimental condition, their data were averaged for each condition. Before starting the experiment two sample texts were presented to familiarize the subject with the procedure; these trials were not scored. No reading text was presented twice to any subject to prevent test repetition effects.

The testing room was dark and quiet to minimize distraction and the influence of other visual or auditory cues on reading. After each reading text a blank screen was presented and a short break of 1–2 min was given to the subject. The whole experiment included short breaks between each text display and did not last longer than 30 min to reduce fatigue effects. To counter effects of spontaneous recovery all the sessions were completed within three days in all patients, and within one day in the normal subjects.

2.5. Scoring of reading errors

The following two types of neglect-related reading errors were scored: (1) omissions of single words on the left- and right side of the text respectively (each omitted word counted as one error). Completely omitted lines of text were not scored because they might represent a qualitatively different category of errors more related to oculomotor disorders (i.e. resulting from the left-sided field defect and/or saccadic disturbances) than reading processes per se (cf Kerkhoff et al., 1992; Schuett, 2009). (2) Stimulus-centered errors: these included omissions of left-sided letter(s), syllable(s) or half of a single word in compound words (i.e. 'keeper' instead of 'housekeeper') and part-word substitutions, when letter(s), syllable(s) or half of a word was substituted (i.e. 'house' instead of 'mouse'). Complete word substitutions were also excluded from the analysis as they may tap into a qualitatively different category of reading problem that is not typical for *unilateral* spatial neglect, since no clear left-right difference with respect to the substituted syllables within the word is evident. See Appendix B for an example of a representative patient with ND.

2.6. Data analysis

As there were ceiling effects in the RBD-control group without ND and the Normal control group (see Appendix C), only the data of the Neglect group were examined with Friedman Tests and Wilcoxon Ranks Test for pairwise comparisons. The dependent variables omission of words and stimulus-centered errors were calculated as relative errors (reading-errors divided by the *number of read words*). Note that for the calculation of relative stimulus-centered errors the omitted words were not counted. The adopted level of significance was 5%.

3. Results

3.1. Quantitative relationship of reading errors

Within the neglect group (in Baseline 1) omissions accounted for 90.2% of all reading errors, whereas stimulus-centered errors accounted for 9.8% of the errors. Omissions in the group showed a clear left–right-gradient, being significantly more frequent on the contralesional than ipsilesional side of the text (56.4% vs. 15.8%) in the first baseline ($Z = -2.66$, $p = 0.008$). The same left–right-gradient was found for stimulus-centered reading errors (6.9% left-sided vs. 0.9% right-sided omissions within words; $Z = -2.19$, $p = 0.028$).

3.2. Omission of words

As only the neglect patient group showed a significant number of reading errors, while the two non-neglect samples performed nearly errorless, we limited the following nonparametric tests reported here (see below) to the neglect patient group. The dependent variable omission of words was examined using a Friedman Test. The results yielded a statistically significant difference in omissions of words on the left side across the four experimental conditions (Baseline 1, OKS-left, OKS-right, Baseline 2; X^2 (df = 3, $n = 9$) = 12.33, $p = .006$). Fig. 2 shows individual error graphs of every neglect patient across the 4 experimental conditions.

Pairwise comparisons (Wilcoxon Rank Tests) showed a significant reduction of errors in the OKS-left condition compared with all other conditions (Baseline 1: $Z = -2.19$, $p = 0.028$, OKS-right: $Z = -2.19$; $p = 0.028$, Baseline 2: $Z = -2.66$, $p = 0.008$) for omissions of complete words. All other comparisons revealed no significant differences (Baseline 1 – OKS-right; Baseline 2 – OKS-right; Baseline 1 – Baseline 2; all $ps > 0.05$). The non-significant difference between Baseline 1 and Baseline 2 indicates a comparable amount of omissions in the two baselines. As can be seen in Fig. 2, 8 out

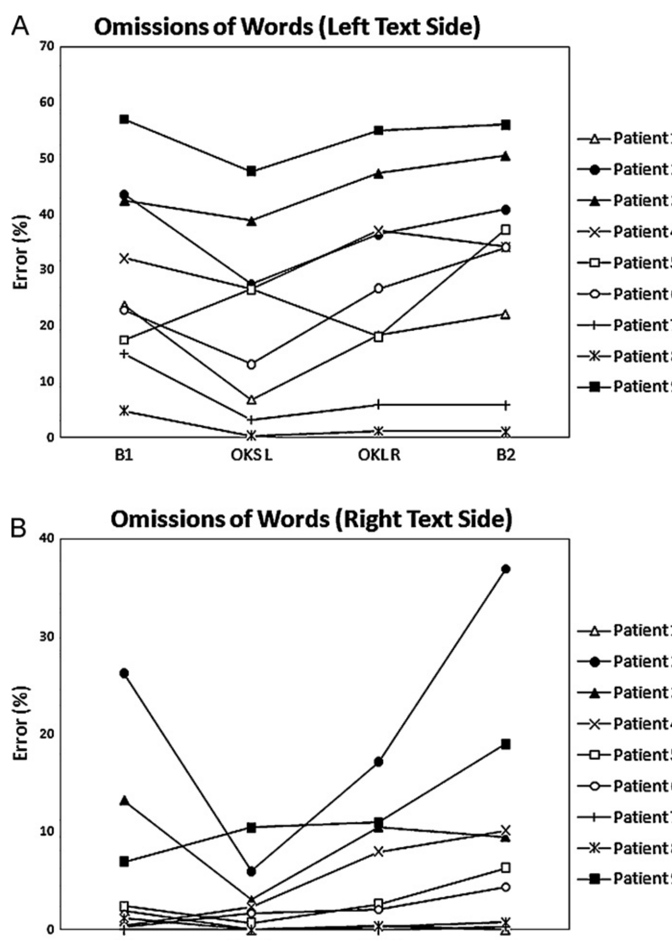

Fig. 2. (A) and (B) Individual error graphs for omissions of whole words for the left (A) and the right (B) text side.

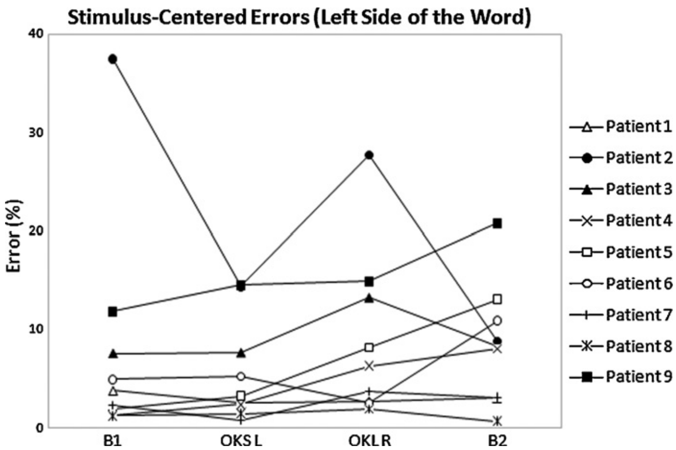

Fig. 3. Individual error graphs for left-sided stimulus-centered errors (omissions of letters or substitutions within words) in the neglect group. Only 3 patients improved in their reading performance, while 6 patients showed a deterioration.

of 9 patients showed a decrease of omission errors in the OKS-left condition compared with the first baseline.

For errors on the right side, a Friedman Test yielded a statistically significant difference in omissions of words across the four experimental conditions (X^2 (df = 3, n = 9) = 10.41, p = 0.015). Wilcoxon Rank Tests showed a significant reduction of errors in the OKS-left condition compared with Baseline 2 ($Z = -2.52$, $p = 0.012$) and OKS-right ($Z = -2.52$; $p = 0.012$. All other comparisons revealed no significant differences (Baseline 1 – OKS-left; Baseline 1 – OKS-right; Baseline 2 – OKS-right; Baseline 1 – Baseline 2; all $ps > 0.05$). Again, the non-significant difference between Baseline 1 and Baseline 2 indicates a comparable amount of omissions in the two baselines. The lack of significance of the comparison of Baseline 1 and OKS-left can be explained by the fact that three patients made nearly no errors on the right text side in the Baseline 1 condition (patients 4, 6, 7; as can be seen in Appendix C).

3.3. Stimulus-centered reading errors

For word-centered errors the results of the Friedman Test showed no statistically significant difference for errors on the left side between all 4 experimental conditions (X^2 (df = 3, n = 9) = 5.40, p = 0.15).

A visual analysis of Fig. 3 reveals that only 3 out of 9 patients showed a numerical decrease in stimulus-centered errors in OKS-left compared with Baseline 2. In contrast, 6 patients showed a decrease in their reading performance (see Fig. 3). Furthermore, there was no significant difference in stimulus-centered errors on the right side of the word across the 4 experimental conditions (X^2 (df = 3, n = 9) = 1.48, p = 0.69).

3.4. Individual analyses of reading errors

Finally, we evaluated whether the lack of any statistical effect of OKS on stimulus-centered reading errors may simply result from a lack of statistical power which would be the case if only a minority of neglect patients in our sample might have shown such errors. Appendix C lists both types of reading errors (omissions and stimulus-centered errors) individually in every neglect patient in comparison to the mean (and minimum as well as maximum) values of the two control groups for the first baseline examination. As is evident from inspection of Appendix C, *every* neglect patient showed *both types* of reading errors although omission errors were more prominent than stimulus-centered errors in most of the patients. Nevertheless, every neglect patient showed a higher

Table 2
Individual error rates for left-sided stimulus-centered errors (omissions of letters or substitutions within words) of the 4 neglect dyslexic patients with higher error rates (5% or more) in each experimental conditions (see text for details). Note that the maximum error rates of normal controls and nondyslexic patients for left-sided stimulus-centered errors in paragraph reading are 0.8%.

Stimulus-centered errors left (%)				
Subject	B1	OKS-L	OKS-R	B2
$N-2$	37.50	14.44	27.72	8.85
$N-3$	7.63	7.70	13.26	8.35
$N-6$	4.99	5.27	2.62	10.92
$N-9$	11.88	14.54	14.93	20.78

rate of neglect-related, left-sided stimulus-centered errors compared to the mean error rates found in the RBD-group without neglect and the healthy control group.

Patients who show higher rates of left-sided stimulus-centered errors are rare (Làdavas, Shallice, & Zanella, 1996) and one could argue, that only in these patients error rates are high enough to be significantly reduced by OKS to the left. Therefore, we analysed the data of the four patients with higher rates of stimulus-centered errors (error rates of 5% or above in the first baseline) separately. As can be seen in Table 1, only one case (patient 2) showed a notable reduction of word-based errors during OKS-left compared with the first baseline. However, compared with the second baseline, error rates of OKS to the left did not differ. Hence, as this reduction of errors falls within the high error variation of patient 2 in the two baselines, we cannot interpret his reduction of word-based errors as an effect of OKS stimulation. The remaining three cases with higher single word error rates showed no modulation of errors during OKS stimulation to the left (see Table 2).

In other words, the lack of a statistically significant modulation of stimulus-centered errors by OKS in the neglect group neither results from a reduced frequency of such errors nor from the possibility that only few neglect patients might have shown such stimulus-centered errors. In fact, none of the neglect patients performed normally with respect to stimulus-centered errors and therefore showed no ceiling-effect like the two control groups. Hence, their performance could have improved significantly with respect to stimulus-centered errors during leftward OKS but this did not occur. As no text was read twice during the experiments these stimulus-centered errors shown in Appendix C do not symbolize perserverations from a previously read text but stand for a specific problem in identifying the initial (left-sided) letters or syllables of read words.

4. Discussion

The present study clearly demonstrates specific effects of OKS on reading performance in a paragraph reading task in ND. The perceptual manipulation used here effectively influenced word omissions but not stimulus-centered errors, as measured simultaneously in the same task with an identical spatial layout. This corroborates findings of our recent study where we found similar results with head-rotation in the same sample (Reinhart et al., 2010). These results have implications for the theory and treatment of ND. On a theoretical level, our findings confirm the independence of these two types of reading errors and suggest the dissociability of the underlying attentional processes and/or spatial reference frames. With respect to the treatment of ND it follows from our results that omissions can be substantially reduced with interventions using manipulations that impact on egocentric reference frames. In contrast, OKS had no positive influence on misreading single words and therefore possibly no influence on processes acting on a word- or stimulus-centered reference frame.

What could be the explanation of this finding on a neural level? At present we can only speculate on this hypothesis in the absence of anatomical data in our ND patients. However, in a recent, large-scale anatomical study on ND, Lee et al. (2009) provided interesting anatomical data in patients with and without ND after unilateral right-hemispheric brain lesions. They found, that lesions of the temporo-parietal cortex caused visual neglect in non-reading tasks. In addition, ND patients had lesions in the right lingual gyrus and the posterior part of the right fusiform gyrus (Lee et al., 2009), which are parts of the ventral stream. Moreover, the right fusiform and lingual gyrus are the homologue area of the so-called *visual word form area* in the left temporal cortex which is believed to be involved in the processing of the visual word form during reading (Cohen et al., 2003). While the left fusiform and lingual gyrus are known to be specifically involved in the primary visual analysis and further processing of the word form, *perception* of the visual word may be processed *bilaterally* in both fusiform and lingual cortices (Cohen et al., 2003). Thus, in analogy to the role of the left visual word form area for single word identification, the right fusiform and lingual gyrus may be crucial for the object-centered spatial processing of a word during reading. Consequently, lesions to the fusiform and lingual gyrus in the *left* hemisphere would produce pure- or word-form dyslexia (Pflugshaupt et al., 2009), while lesions to the homologue area in the *right* cerebral hemisphere would cause neglect dyslexia. Additional damage to adjacent areas in the temporo-parietal cortex would result in additional neglect generalizing to non-reading tasks (Lee et al., 2009). In accordance with this hypothesis, the right parahippocampal cortex in the ventral visual stream has been found to be involved in object-centered neglect in visual search tasks (Grimsen et al., 2008).

To conclude, we suggest that stimulus-centered reading errors in neglect are not modulated by OKS as such word-related information is not primarily processed in the dorsal visual stream. Instead, this information is preferentially processed in the right fusiform and lingual gyrus as parts of the ventral visual stream. As the ventral visual stream is not devoted to egocentric spatial processing (Hillis et al., 2005; Vallar et al., 1999) egocentric manipulations via OKS are unlikely to exert a significant influence on the visual processing of *word*-related information in ND. In fact, a recent OKS-treatment study in neglect patients (Thimm et al., 2009) showed significant activity changes in the left and right parietal cortex (as assessed by functional magnetic resonance imaging) which is consistent with both the observed modulation effect of OKS on omission errors in neglect dyslexia and the absence of such an effect on word-based errors in ND.

Other studies that presented single words at the fixation point found positive effects of sensory stimulation on single word reading (Schindler & Kerkhoff, 1997). However, by presenting single words at the central fixation, the egocentric, the stimulus-centered, and the word-centered reference frames all are aligned. The positive effects of OKS or other sensory-perceptual manipulations may be restricted to (pre-)attentional processes acting on the egocentric reference frame. However, when the reference frames are aligned, the OKS-stimulation could be sufficient to positively affect single word reading processes acting on stimulus- or word-centered reference frames. In our study, egocentric and stimulus-centered reference frames were separated. During paragraph reading single words are fixated serially to process the visual features to abstract letter strings as suggested by Caramazza and Hillis' model (1990a). Furthermore, attention has to be horizontally distributed during reading moving from the previous to the next word in order to read the content of the sentence. Hypothetically, facilitating attentional shifts to the egocentric left side is not sufficient to enhance single word reading if attention has to be distributed over a wider spatial area such as a text paragraph compared to focal attention processes deployed on a single word.

Positive effects of moving dots are commonly explained by triggering the optokinetic reflex which re-centers the pathological ipsilateral distortion of the egocentric co-ordinate system relating to the midsagittal plane of the body (Karnath, 1994). Other authors explain the effects by smooth pursuit eye-movements tracing the eyes to the neglected hemifield. Both are triggered by *foveally* attaching the image of the moving object on the retina. Interestingly, we found a reduction of omissions in the left hemifield with moving dots to the left that only *surrounded* the reading field in the visual periphery and not moving centrally through the text or the words. Therefore, it seems highly unlikely that OKS improved reading via optokinetic nystagmus because if such a nystagmus were present it would certainly disrupt reading to the right side. Alternate accounts of the mechanisms by which OKS improves left-sided neglect assume a facilitation of lateralized attentional processes which in turn improve the exploration and awareness of the neglected hemispace. The present results of a reduction of word omissions in ND induced by leftward OKS are more compatible with the hypothesis that OKS triggers (pre-)attentional processes (Chokron, 2003; Chokron et al., 2007; Gainotti, 1996; Kerkhoff, Keller, Ritter, & Marquardt, 2006) than with the hypothesis that OKS re-centers a pathological ipsilateral distortion in patients with left-sided neglect (Karnath, 1994), at least in the present context of paragraph reading.

Finally, as mentioned above, stimulus-centered reading errors are less frequent than omissions but nevertheless relevant. Misreading single words makes a paragraph incomprehensible as well as omissions of whole words. Hence, treatments for curing stimulus-centered reading errors in ND are necessary, but probably require the development of combined therapy approaches that specifically influence stimulus- or word-centered attention in text reading.

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Appendixes A and B.

Example of the reading performance of a neglect dyslexic patient in the first baseline (A) and with OKS left (B). Omissions are shaded in grey, stimulus-centered errors are framed.

OB DIE ALLWISSENDEN STERNDEUTER
WIRKLICH IMMER RECHT EBEN, DAS MUSS NATÜRLICH
JEDER SELBST NACHPRÜFEN. BEI DEN
ECHTEN WIDDERN, DEN MÄNNLICHEN SCHAFEN MIT DEN
DICKEN HÖRNERN, STIMMT ES ALLEMAL.
IMMER MIT DEM KOPF VORAUS, OHNE RÜCKSICHT AUF
VERLUSTE, BENENNEN SIE GEGEN JEDEN FEIND ODER
NEBENBUHLER AN, UM IHN ZU VERNICHTEN.

SO EIN BAU EINES MURMELTIERES BESTEHT AUS
VIELEN SCHÄCHTEN, GÄNGEN UND GRUBEN UND IST EIN
WEITVERZWEIGTES SYSTEM. JEDER BAU WIRD
JEDOCH IMMER NUR VON EINER EINZIGEN FAMILIE BEWOHNT.
WENN DIE TIERE AUS IHREN LÖCHERN KOMMEN,
DANN HUSCHEN SIE ZUERST ZU EINER KLEINEN ROHMULDE,
DIE VOR EINEM BAU LIEGT. JEDES TIERCHEN REIBT
SICH DIE NACKEN IN DER MULDE UND MEIST
IMMER NUR DANN HINTERLÄSST ES DAMIT SEINEN
ERKENNUNGSDUFT

Appendix C.

Individual error data of spaced-based-errors (omissions) and stimulus-centered reading errors (%) in the left and right hemispace (left vs. right side of the displayed texts) during the first baseline tests in the neglect patients (Patient numbers correspond to those in Table 1).

	Omission errros (%)		Stimulus-centered errors (%)	
Subject	Left	Right	Left	Right
N − 1	23.73	1.94	3.82	0.00
N − 2	43.50	26.23	37.50	0.00
N − 3	42.51	13.22	7.63	0.69
N − 4	32.12	0.50	1.35	0.00
N − 5	17.52	2.46	1.91	0.47
N − 6	22.85	0.37	4.99	1.36
N − 7	15.09	0.00	2.36	1.80
N − 8	4.83	1.22	1.30	3.89
N − 9	57.00	7.00	11.88	3.13
Controls				
Mean RBD	0.17	0.00	0.34	0.63
(min–max)	(0–0.8)	(0–0)	(0–0.8)	(0–1.6)
Mean normal	0.00	0.00	0.13	0.07
(min–max)	(0–0)	(0–0)	(0–0.4)	(0–1.2)

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