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Repetitive optokinetic stimulation induces lasting recovery from visual neglect

G. Kerkhoff[a,*], I. Keller[b], V. Ritter[c] and C. Marquardt[d]
[a]*Clinical Neuropsychology Unit, Saarland University, Saarbrücken, Germany*
[b]*Neurologische Klinik, Bad Aibling, Germany*
[c]*Neurological rehabilitation clinic, Ulm University, Germany*
[d]*EKN-Neuropsychology Research Group, Hospital Bogenhausen, München, Germany*

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Abstract. *Purpose*: To evaluate whether repetitive optokinetic stimulation with active pursuit eye movements leads to substantial and greater recovery from visual neglect as compared to conventional visual scanning training.
Methods: Two groups of five patients with leftsided hemineglect were consecutively collected and matched for clinical and demographic variables as well as neglect severity. One group received five treatment sessions of repetitive optokinetic stimulation (R-OKS) within one week, while the other group received the same amount of conventional visual scanning training (VST) using identical visual stimuli and setup. All patients were treated in a single-subject baseline design with treatment-free intervals before (14 days) and after specific neglect therapy (14 days). Dependent variables were the improvements in digit cancellation, visuoperceptual and visuomotor line bisection and visual size distortion during treatment. The transfer of treatment effects was assessed by a paragraph reading test.
Results: The results showed superior effects of OKS treatment in all five patients which generalized across all tasks administered and remained stable at follow-up. In contrast, no significant improvements were obtained after VST training in any of these tasks, except in line bisection.
Conclusion: We conclude that the presentation of *moving* visual stimulus displays with active smooth pursuit eye movements can be more efficient than conventional visual scanning training using *static* visual displays.

Keywords: Brain damage, neglect, visual motion, rehabilitation, therapy, recovery

Abbreviations: OKS: optokinetic stimulation, VST: visual scanning training

1. Introduction

Hemineglect denotes the impaired or lost ability to react to or process sensory stimuli (visual, auditory, tactile, olfactory) presented in the hemispace contralateral to the lesioned cerebral hemisphere. Despite recovery of the most obvious signs of hemineglect in the first 2–3 months after stroke a considerable portion of neglect patients – especially those with *large* right-hemispheric lesions – remains severely impaired in visual scanning, reading and functional activities of daily living (ADL) [10,14]. Furthermore, neglect patients have a delayed recovery from hemiplegia [3], often display postural problems [31] and suffer from a poor long-term outcome as compared to patients without neglect. Few neglect patients recover in a way that allows them to live independently or even return to work. Since its

*Corresponding author: Prof. Dr. G. Kerkhoff, Clinical Neuropsychology Unit, Saarland University, Faculty of Social Sciences, Postbox 15 11 50; D-66041 Saarbrücken, Germany. E-mail: kerkhoff @mx.uni-saarland.de.

introduction by Diller and colleagues [4] visual scanning training (further abbreviated VST) has been used successfully as a treatment for neglect [1]. However, VST is often laborious, requires numerous treatment sessions (i.e. about 40 [16]) shows little transfer to activities of daily living [29] and has no effect on nonvisual neglect [35]. Another drawback of VST is that it is based on *top-down mechanisms* requiring a conscious compensatory strategy – which is often difficult for the acute patient due to unawareness of the symptoms. Consequently, treatments based on *bottom-up mechanisms* which do not require explicit awareness of the deficits may be more successful in these patients.

In the last decade a variety of sensory stimulation techniques (for review, see [18]) have shown that virtually every aspect of neglect behaviour can be significantly, though transiently improved by such techniques. The basic idea underlying all sensory stimulation approaches in neglect patients is that neglect results from a disrupted representation and/or transformation of spatial coordinates into a common frame of reference necessary for accurate orientation of the subject in space. Since multiple sensory and proprioceptive informations are fed into such a hypothetical reference frame, many of these input channels have been used to manipulate the neglect symptomatology by varying this input.

One of these techniques, optokinetic stimulation (OKS [27]) or repetitive optokinetic stimulation [17]), is based on visual displays of numerous stimuli all moving coherently to the patient's neglected side. This technique positively affects several aspects of the neglect syndrome. Leftward OKS temporarily reduces the ipsilesional line-bisection error [22,27], alleviates the ipsilesional deviation of the subjective visual straight ahead [13] and it transiently decreases visual size-distortion in neglect patients [19]. Moreover, OKS effects are not limited to *visual* neglect. Vallar and colleagues described significant positive effects of leftward large-field OKS on position-sense in the contra- and ipsilesional arm of patients with leftsided neglect [37,38]. Furthermore, grip-strength could be temporarily improved in two patients with leftsided hemiparesis and leftsided neglect by viewing large-field OKS moving to the neglected side [39]. Finally, leftward OKS temporarily reduces tactile extinction of the contralesional hand [24]. Interestingly, OKS induced by high velocities is not necessary to obtain modulatory effects on neglect, or is inefficient [26]. Beneficial effects occur also with low velocities ($<10°$/sec [22]), and relatively small stimulus displays ($30° \times 20°$ [34]). Although this might induce optokinetic nystagmus, it may be questioned whether the crucial effect is based on the nystagmus or other factors (see Discussion).

Despite the modulatory but mostly *transient* effects of OKS on all aspects of the neglect syndrome few studies have been conducted to use it for the treatment of neglect. Here, we report the results of a pilot study with ten neglect patients to evaluate the therapeutic potential of *repetitive* optokinetic stimulation (OKS) in comparison with Visual Scanning Training (VST) in neglect therapy. In addition to asking whether OKS has measurable and permanent therapeutic effects we were also interested to learn whether such effects generalize across different domains of the neglect syndrome, i.e. cancellation, reading, visuomotor and visuoperceptual line bisection as well as size distortions.

2. Patients and methods

2.1. Patients

Ten patients with leftsided chronic neglect (time post lesion >2 months) were tested with a battery of neglect screening tests (Table 1). The first five patients were allocated to the group receiving optokinetic stimulation (OKS), the next five patients (termed VST-group) were collected to match the patients in the OKS-group with regards to clinical and demographic variables as well as neglect severity in the baseline tests.

2.2. Tests

Cancellation tests: Patients were instructed to cancel with a pen in their right hand, two types of digits (i.e. all tokens of "1" and "9") distributed randomly among 200 single digits ranging from "0" – "9" presented on a 29×21 cm white piece of paper in front of the patient. Three tests were performed at each measurement point. The number of omissions in the left and right hemifield was counted (max. 20 per hemifield).

Reading tests: To examine the transfer to a non-trained but important activity of daily living, 25 parallel paragraph reading tasks were developed for the assessment of neglect dyslexia. Each text had on average 55 words (range: 52–58) arranged in 6 lines with irregularly indented margins on both sides (arial font, point size 12, double line spacing, size of the text: 25 cm horizontal and 9 cm vertical). Reading texts were presented centrally on a 17" PC monitor at a distance of 0.4 m from the patient. Five texts were presented suc-

Table 1
Demographic and clinical data of 10 neglect patients in the two treatment groups. In cancellation, the number of omissions on the left/right side of the page are listed (Cutoff: max 10% per hemifield); Line bisection: horizontal deviation from true midline in mm (Cutoff: $+/-$ 5 mm); neglect dyslexia: omissions in a 180 word reading test. MCI: middle cerebral artery infarction; ICB: intracerebral bleeding; T: temporal, P: parietal, O: occipital, BG: basal ganglia

Patient code	Treatment	Age, Gender	Etiology, Months since Lesion	Lesion location	Motor/ sensory loss left side	Visual field, Field Sparing (°)	Cancell. Omissions L/R (%)	Line bisection deviation L/R (mm)	Neglect-dyslexia
OKS-1	OKS	50, m	MCI-R, 5	T,P	$+/+$	left quadran-tanopia, 6°	60/20	$+8$	moderate
OKS-2	OKS	74, f	MCI-R, 3	P	$+/+$	left hemianopia, 3°	100/70	$+80$	severe
OKS-3	OKS	54, m	MCI-R, 3	T, P	$+/+$	left hemianopia, 4°	30/00	$+41$	severe
OKS-4	OKS	55, m	MCI-R, 3	T, BG	$+/+$	left quadran-tanopia, 10°	30/00	-2	moderate
OKS-5	OKS	37, f	MCI-R, 3	T, P	$+/+$	left hemi-amblyopia 5°	30/00	0	no
Median/ mean	–	**54 yrs**	**3 months**	–	–	–	**50/18**	**+27.4 mm**	–
VST-1	VST	69, m	MCI-R, 2	T, P	$+/+$	left hemianopia 3°	50/10	$+25$	severe
VST-2	VST	50, m	MCI-R, 3	T, BG	$+/+$	left hemianopia, 5°	90/40	-11	moderate
VST-3	VST	60, m	MCI-R, 2	T, O	$+/+$	left hemianopia, 8°	50/20	$+13$	severe
VST-4	VST	57, f	ICB-R, 5	T,P	$+/+$	left hemianopia 3°	80/10	$+39$	moderate
VST-5	VST	53, f	MCI-R, 3	T,P	$+/+$	left hemianopia 4°	30/00	$+70$	moderate
Median/ mean	–	**57 yrs**	**3 months**	–	–	–	**60/16**	**+31.6 mm**	–

cessively on each measurement. Two types of errors were analysed: omissions of words (space-based errors) and substitutions of words or word-parts (word-or object-centered errors). In addition reading time was recorded with a stopwatch.

Line bisection: Visuoperceptual horizontal line-bisection was tested with VS, a computerized test system for the analysis of spatial perception [17]. A 25 $\times$ 1 cm yellow horizontal bar was presented centrally on a screen at a distance of 40 cm from the patient. On the right side of the bar a small vertical slit was visible (0.2 cm wide) which had to be positioned towards the patient's subjective midline position. No manual performance was allowed by the patient, who indicated verbally to the examiner how to position the slit into the midline position. Ten trials were performed on each measurement. Visuomotor line bisection was tested with a paper and pencil test. A 20 cm long and 5 mm wide black horizontal line was presented centrally on a 29 $\times$ 21 cm large white piece of paper. The patient was instructed to bisect the line with a pencil using his/her right hand. Three trials were performed at each measurement point on separate test sheets.

All tests were untimed; only in the paragraph reading test reading tímes were taken with a stopwatch.

2.3. *Repetitive optokinetic stimulation* (*OKS*)

Visual stimuli were presented on a 17" PC monitor (eccentricity: 22.4° horizontal, 17.4° vertical). The patients were instructed to look at computer-generated random displays of 30–70 dots (2–4 cm in diameter) on a dark background, using specifically designed software (EyeMove, www.Medical-Computing.de). All dots moved coherently towards the left, contralesional hemispace with a speed of 7.5–50°/s. Movement speed was varied from trial to trial to keep patients alert. Subjects were encouraged to make smooth pursuit movements towards the direction of the motion and return with their eyes repeatedly to the ipsilesional side of the screen. No head movements were allowed. Every 10 minutes a break was given for a few minutes without OKS-stimulation. Thus, in every therapy session 4 runs of OKS à 10 minutes duration were practiced (see Fig. 1A)

2.4. *Visual scanning treatment* (*VST*)

The five control patients received the same amount of neglect treatment as the OKS group, using the same device and stimuli (see above), yet with the important difference that all visual stimuli displayed on the screen remained *stationary.* Patients were instructed to scan the stimuli in a systematic way starting on the left top to the right bottom of the screen (see Fig. 1B). Scanning strategies were repeatedly explained to the patients and the timing of treatment and breaks was identical to the OKS group. Patients were encouraged to make (saccadic) eye movements and scan to the left side as far as possible. Head movements were not allowed. Thus, in every therapy session 4 runs of VST à 10 minutes duration were practiced. Hence, the crucial difference between the two treatments lay in the moving vs. stationary character of the visual stimuli, and subsequently,

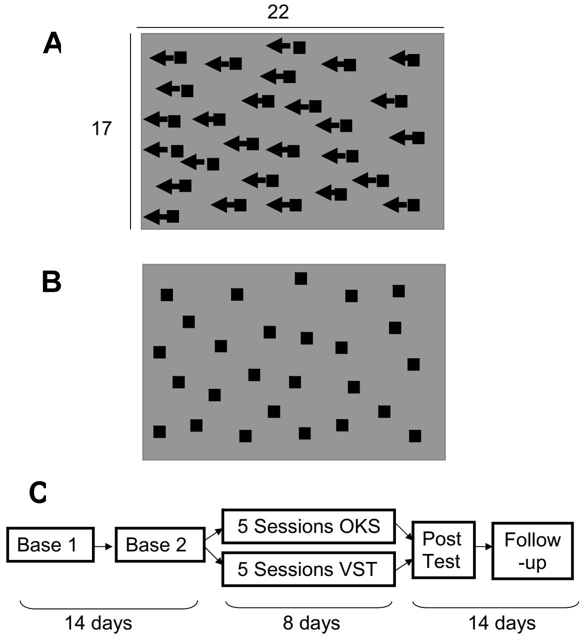

Fig. 1. Schematic illustration of the setup for the optokinetic stimulation training (A) and the visual scanning treatment (B), and the design of the study (C). For details see text. Note, that the arrows in Fig. A only show the direction of motion, they were not visible for the patient.

in the type of eye movements exacted by the patient (saccades in the VST vs. pursuit eye movements and saccades in the OKS group).

2.5. *Design*

Every patient was studied in a single subject baseline design with a treatment-free interval of 14 days *before* the specific neglect therapy (OKS or VST) and an identical follow-up period of 14 days after this period. During the 14-day baseline period all subjects were tested three times (twice in the bisection and size distortion tasks, respectively) in all neglect tests to exclude effects of spontaneous recovery and/or test repetition or the influence of other therapies. The follow-up period served to test the stability of improvements. The day after the last baseline assessment specific neglect treatment was started (either OKS or VST) and performed for five sessions (à 45 minutes, delivered in a period of seven to ten days). All neglect tests were repeated on the day after the fifth treatment session and 14 days after this post-test a follow-up investigation was performed (see Fig. 1C). Apart from the specific neglect treatment, all patients received standard occupational therapy and physiotherapy – but no neglect nor attentional nor reading training – throughout the *complete* course of the study (hence during baseline, treatment and follow-up periods in both treatment groups).

3. Results

Due to the small samples all statistical analyses were run separately for both patient groups with nonparametric tests over all single trials in the five patients of each group. Friedman nonparametric analyses of variance were used to test for overall effects over time and paired comparisons were performed with Wilcoxon-tests (two-tailed, $p < 0.05$, Bonferroni-correction).

3.1. *Comparison of the two treatment groups before neglect therapy*

Both treatment groups were comparable with respect to clinical and demographic variables (see Table 1). In addition, we compared the two treatment groups via Mann-whitney tests with respect to the outcome variables on the last baseline measurement before specific neglect treatment was started. No significant differences were obtained for any of the seven outcome variables detailed in the results section (largest U-value: 182.0, smallest p-value: 0.075). Taken together, these results show that both groups were comparable regarding demographic and clinical variables as well as neglect severity before treatment.

3.2. *Cancellation*

In the OKS group the Friedman-test revealed a significant main effect over time for the number of leftsided (contralesional) omissions ($\chi^2 = 34.4$, $df = 4$, $p < 0.0001$). Post-hoc Wilcoxon-tests revealed no significant change between the first and third baseline $z = -1.9$, $p > 0.05$). After OKS treatment the percentage of leftsided omissions in cancellation had significantly decreased relative to the third baseline ($z = -3.7$, $p < 0.0001$; see Fig. 2A). These improvements were maintained from the post-test to the follow-up test ($z = -1.1$, $p > 0.05$). In contrast, no significant effect was found for the number of rightsided (ipsilesional) omissions ($\chi^2 = 6.5$, $df = 4$, $p > 0.05$). This result was mainly due to the small percentage of rightsided omissions in three neglect patients with moderate visual neglect (ceiling effect). The mean percentage of rightsided omissions ranged between 8.3%

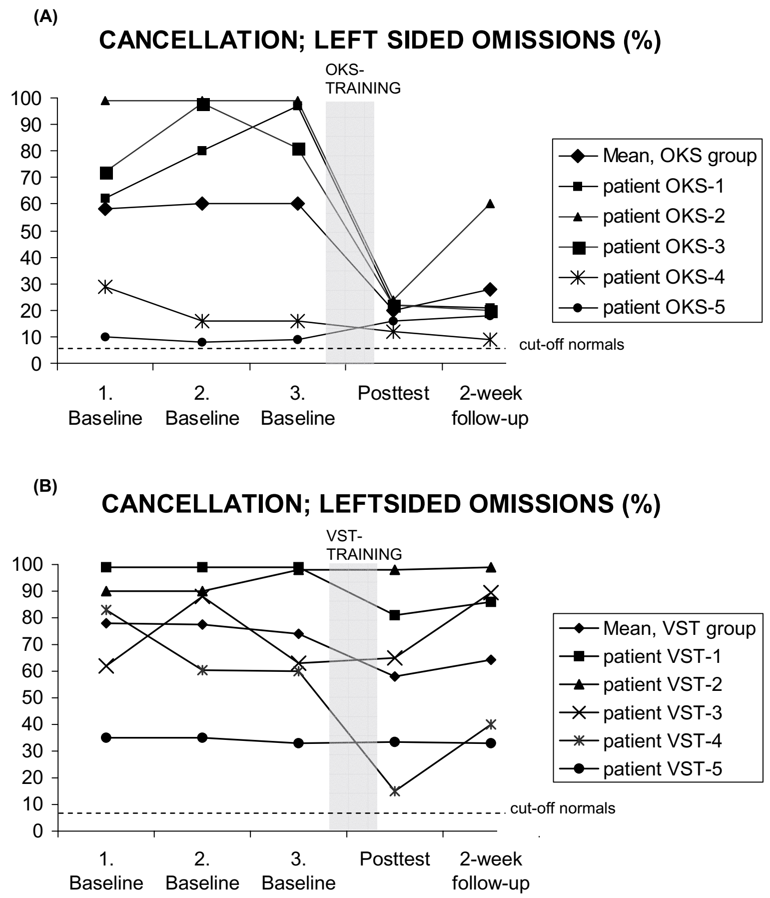

Fig. 2. Effects of repetitive optokinetic stimulation (OKS, **A**) and visual scanning training (VST, **B**) on the percentage of contralesional (leftsided) omissions in digit cancellation. Single graphs of five patients are displayed (individual mean values and group mean; see legend). Note the stability of deficits over the baseline period, and the significant reduction of omissions after treatment which remained stable at follow-up. The shaded area indicates the treatment period, the dotted line shows the normal cutoff in this task. For patient codes see Table 1.

and 28% in the five patients over the five measurement points.

In the VST group the Friedman-test revealed no significant effect over time for the number of leftsided (contralesional) omissions ($\chi^2 = 6.541$, $df = 4$, $p > 0.05$; see Fig. 2B). Furthermore, no significant effect for the number of rightsided (ipsilesional) omissions was found over time ($\chi^2 = 8.473$, $df = 4$, $p > 0.05$) although there was a nonsigificant trend towards a reduction of rightsided omissions after VST-training (exact $p = 0.076$). The mean percentage of rightsided omissions ranged from 19% to 39 % in the 5 patients over all measurement points.

3.3. *Line bisection*

For *perceptual* line bisection (on the PC screen) there was a significant effect over time in the OKS group ($\chi^2 = 46.5$, $df = 3$, $p < 0.001$). Subsequent Wilcoxon-tests revealed a significant deterioration in performance from the first to the second baseline ($z = -4.5, p < 0.001$). After OKS the rightsided deviation in line bisection was significantly reduced as compared to the second baseline ($z = -5.3, p < 0.001$; see Fig. 3A). These improvements were maintained from the post-test up to the follow-up ($z = -0.7, p > 0.05$).

In the VST group there was also a significant effect over time in perceptual line bisection ($\chi^2 = 29.6$, $df = 3$, $p < 0.0001$). Subsequent Wilcoxon-tests revealed a significant deterioration in performance from the first to the second baseline ($z = -2.9, p < 0.005$). After VST the rightsided deviation in line bisection was significantly reduced as compared to the second baseline ($z = -5.5$, $p < 0.0001$; see Fig. 3B). These improvements remained stable from the post-test up to the follow-up test ($z = -1.2, p > 0.05$).

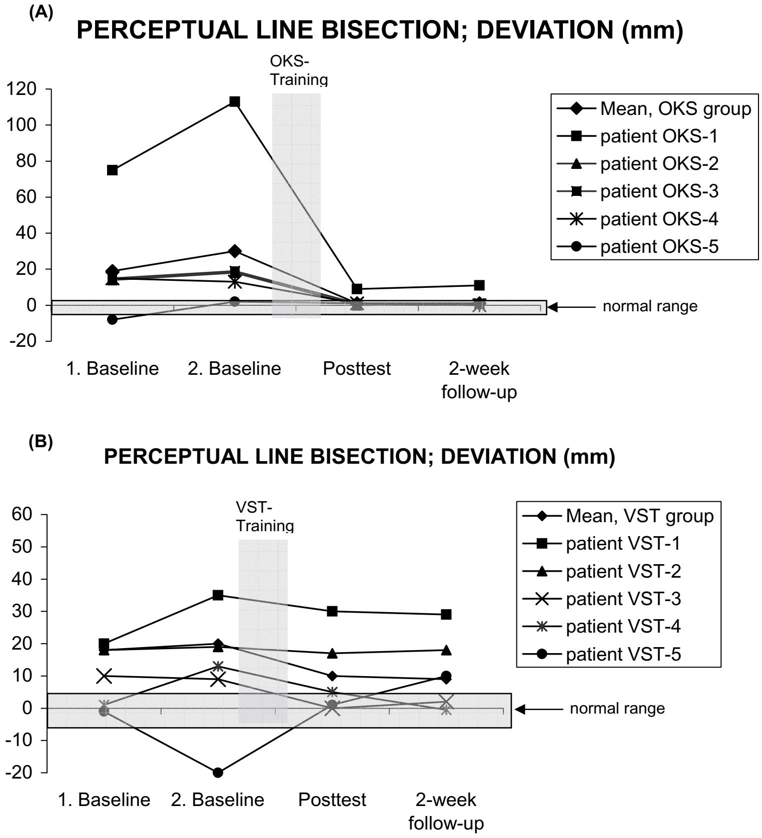

Fig. 3. Effects of repetitive optokinetic stimulation (OKS, **A**) and visual scanning training (VST, **B**) on visuoperceptual, horizontal line bisection. The deviation from the true midline is displayed (in mm; $-/+$ denote left-/rightward deviations from the true midline). Note the deterioration of deficits over the baseline period, and the significant reduction of the deviation after treatment which remained stable at follow-up. The shaded area indicates the treatment period, the striped area indicates the normal range. Patient codes as in Fig. 2.

For manual (*visuomotor*) line bisection there was a significant effect over time in the OKS group ($\chi^2 = 19.8$, $df = 3$, $p < 0.0001$). Post-hoc Wilcoxon-tests revealed no significant difference in performance between the first and the second baseline ($z = -0.1$, $p > 0.05$). After OKS therapy visuomotor line bisection had significantly improved as compared to the second baseline ($z = -2.6$, $p < 0.005$; see Fig. 4A). These improvements were maintained between the post- and follow-up test ($z = -0.2$, $p > 0.05$).

In the VST group no significant effect over time was observed for *visuomotor* line bisection ($\chi^2 = 0.3$, $df = 3$, $p > 0.05$; see Fig. 4B).

3.4. Size distortion

A significant main effect over time was found in the OKS group for the extent of the visual size distortion in the length judgment task ($\chi^2 = 19.0$, $df = 3$, $p < 0.0001$). No significant change was observed between the first and second baseline ($z = -1.6$, $p > 0.05$). After OKS-therapy the size distortion was significantly reduced as compared to the second baseline ($z = -4.1$, $p < 0.0001$; see Fig. 5A). These improvements were maintained from the post-test up to the follow-up test ($z = -2.0$, $p > 0.05$). Three of the five patients showed the typical size distortion during baseline (overreproduction of the horizontal length of the bar in the contralesional, left hemispace). This deficit improved in all three cases after treatment. The other two cases showed no stable size distortion before treatment and did not show any consistent change over time.

No significant effect over time was found for the extent of the visual size distortion in the VST group ($\chi^2 = 3.2$, $df = 3$, $p > 0.05$; see Fig. 5B). Four of the five patients showed the typical size distortion over nearly all measurement dates, with the exception of patient VST-2 who scored in the normal range in the first baseline test. In none of these four patients a

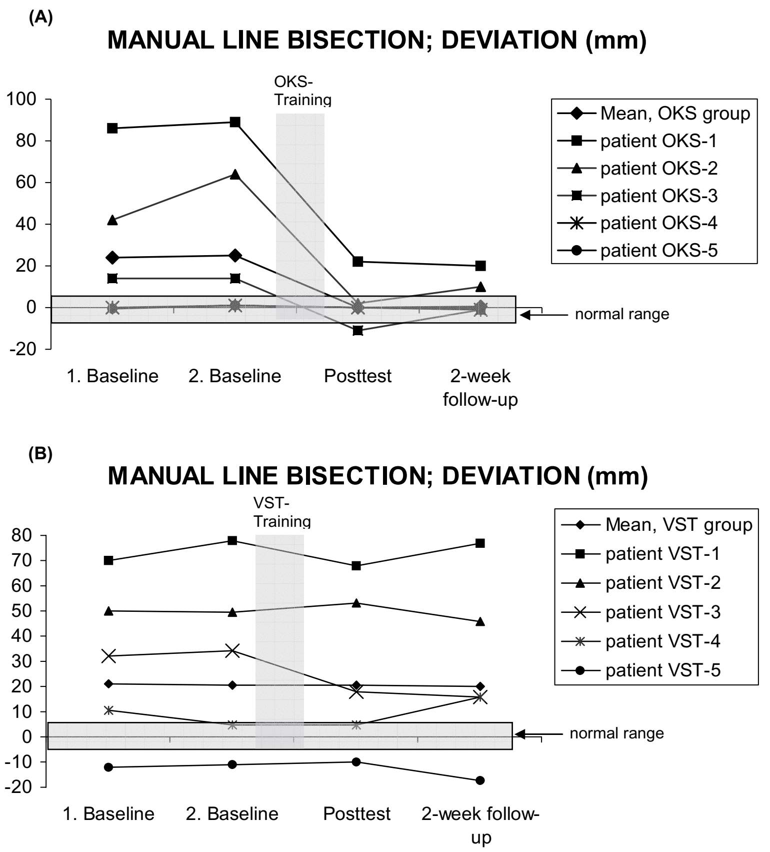

Fig. 4. Effects of repetitive optokinetic stimulation (OKS, **A**) and visual scanning training (VST, **B**) on visuomotor (manual), horizontal line bisection. Note the stability of deficits over the baseline period, and the significant reduction of the deviation after treatment which remained stable at follow-up. The shaded area indicates the treatment period, the striped area indicates the normal range. Patient codes as in Fig. 2.

significant change was observed after VST. The fifth patient in the VST group did not show a consistent size distortion over the four measurement points.

3.5. *Reading*

The Friedman-test revealed a significant main effect over time for the number of omissions ($\chi^2 = 34.4$, $df = 4$, $p < 0.0001$). No significant change was observed between the first and third baseline ($z = -1.9$, $p > 0.05$) although there was a trend for a nonsignificant deterioration from the first to the third baseline test (see Fig. 6A). After OKS reading had improved significantly in the posttest as compared to the third baseline ($z = -3.7$, $p < 0.0001$). These improvements were maintained from the post-test up to the follow-up ($z = -1.1$, $p > 0.05$).

In contrast, no improvement was observed regarding object-based reading errors (substitutions; $\chi^2 = 4.3$, $df = 4$, $p > 0.05$). The mean error rates for substitutions were: Base 1: 2.7%, Base 2: 2.0%, Base 3: 2.7%, Posttest: 2.3%, Follow-up: 2.1%).

Finally, mean reading times (per condition) were compared over the five measurements. There was no significant effect over time ($\chi^2 = 6.5$, $df = 4$, $p > 0.05$) showing that the reduction of omissions after treatment reported above did not occur as a result of increased time spent during the reading tasks. However, there was a numerical but statistical nonsignificant trend for longer reading times at the post- und follow-up test. The mean reading times (per text) for the five measurements were: Base(line) 1: 58.9 s (seconds), Base 2: 54.8 s, Base 3: 61.1 s, Posttest: 70.5 s, Follow-up-test: 76.4 s.

In the VST group no significant effect over time was observed for the number of omissions in the paragraph reading test ($\chi^2 = 6.8$, $df = 4$, $p > 0.05$). Likewise, no significant change over time was observed with respect to object-based reading errors (substitutions; $\chi^2 = 2.1$, $df = 4$, $p > 0.05$). The mean er-

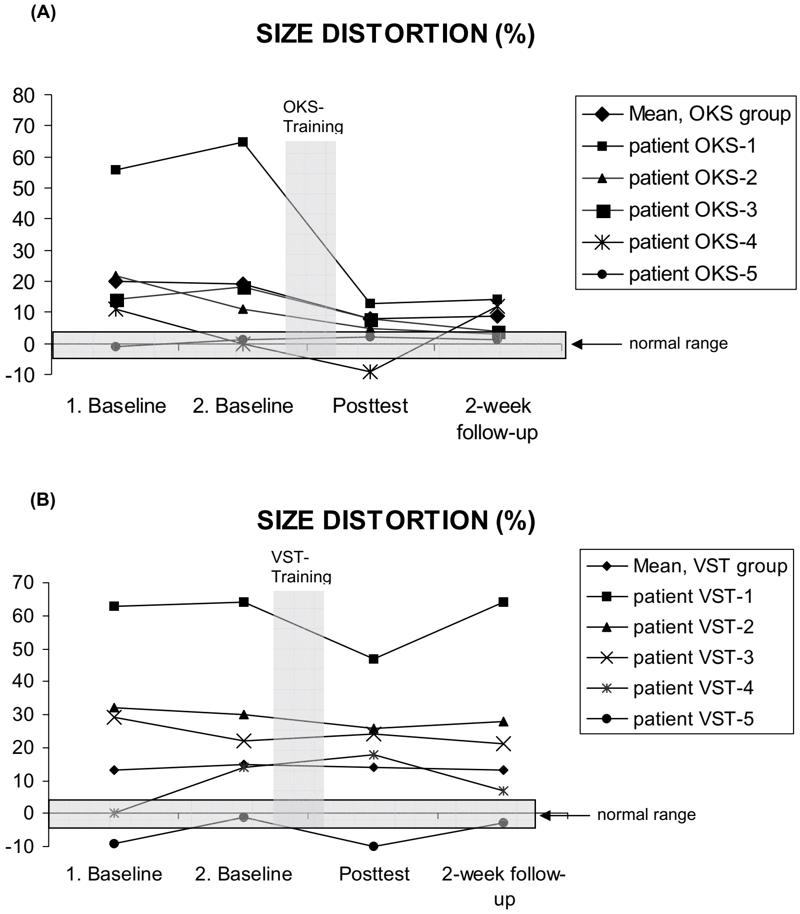

Fig. 5. Effects of repetitive optokinetic stimulation (OKS, **A**) and visual scanning training (VST, **B**) on the horizontal visual size distortion ($+/-$ denotes over- or underestimation of the left line segment in % compared to the reference bar). Single graphs of five patients are displayed (individual mean values and group mean). Note the stability of the size distortion over the two baselines in three neglect patients, and their improvement after OKS. Two subjects did not show size distortions. Patient codes as in Fig. 2.

ror rates for substitutions were: Base 1: 2.9%, Base 2: 2.3%, Base 3: 1.7%, Posttest: 2.8%, Follow-up: 2.9%). Finally, mean reading times (per condition) were compared over the five measurement dates. There was a significant effect over time ($\chi^2 = 10.0$, $df = 4$, $p < 0.05$). Wilcoxon tests showed that the reading time increased significantly from the second to the third baseline ($z = -2.5, p < 0.05$). Furthermore, the reading time at the follow-up was significantly longer as that during the first ($z = -2.2, p > 0.05$) and the second baseline ($z < 0.05$). All other paired comparisons were not significantly different (largest $z = -1.559$, smallest $p = 0.119$). The mean reading times (per text) for the five measurements were: Base(line) 1: 57.6 seconds (s), Base 2: 53.3 s, Base 3: 62.9 s, Posttest: 58.6 s, Follow-up-test: 64.9 s.

3.6. Mean improvements and their stability

In order to make the improvements and stability of the obtained improvements during therapy more comparable we computed the average change (in %) after training as compared to averaged pre-treatment baseline values for each test and treatment group separately (Table 2). Similarly, we computed a measure of stability by comparing the mean change (in %) from averaged pre-treatment baseline values to the follow-up-test. When both measures yield similar values this indicates relative stability of the treatment effects. As is obvious from Table 2 the values for improvement and stability are nearly identical for most test variables in both groups, but in toto are about five times higher in the OKS group than in the VST group.

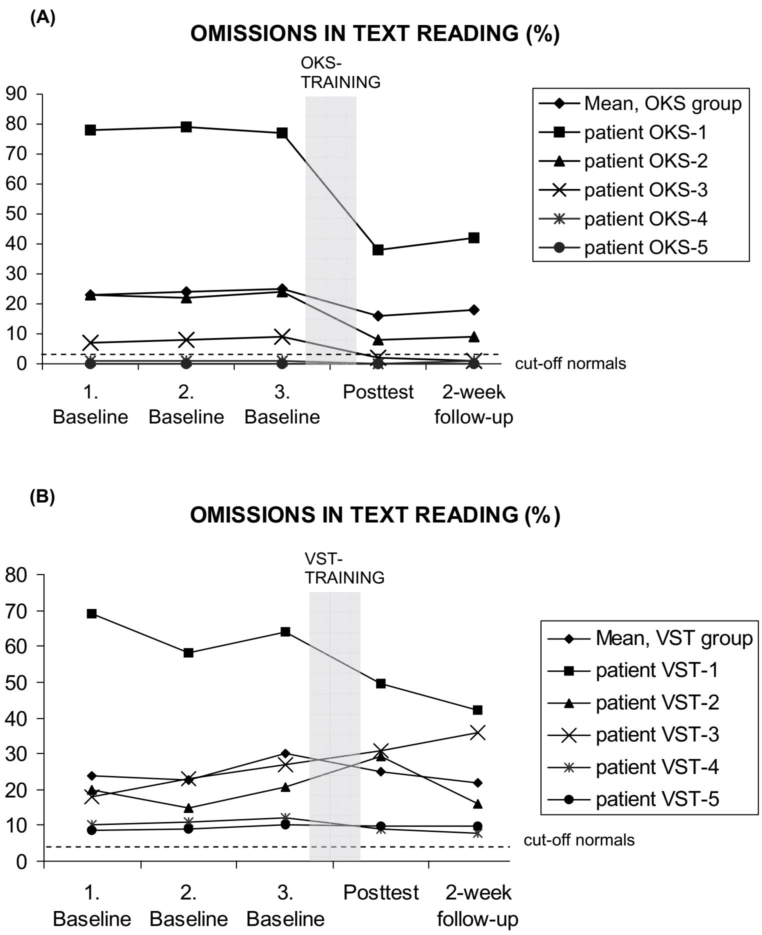

Fig. 6. Effects of repetitive optokinetic stimulation (OKS, **A**) and visual scanning training (VST, **B**) on the percentage of omissions in paragraph reading. Single graphs of five patients in the group receiving repetitive optokinetic stimulation (OKS) are displayed (individual mean values and group mean). Note the stability of neglect in reading during the baseline period in all patients. Patient codes as in Fig. 2.

4. Discussion

Two main findings are apparent from this pilot study: 1) repetitive OKS has therapeutic effects in a wide variety of visual neglect tasks, showing that the obtained improvements generalize across several domains of neglect, different tasks as well as different input/output modes (i.e. in line bisection). Furthermore, OKS is more effective than conventional visual scanning training. 2) OKS has similar therapeutic effects as other novel therapeutic techniques, i.e. attentional and limb activation training [28,30], neck muscle vibration [35] or prism adaptation [8]. The subsequent discussion will deal with these two main aspects.

4.1. General therapeutic effects of OKS

To our knowledge this is the first successful study showing significant therapeutic effects after a small number of OKS treatment sessions in patients with moderate to severe visual neglect. Previous authors using slow visual motion have indeed suggested that *repetitive* motion stimuli might constitute a promising treatment technique [22], although a recent study did not obtain additional positive effects of OKS training in neglect therapy [26]. The improvements obtained in the present study clearly demonstrate that this may be achieved. The improvements covered different domains of neglect (cancellation, reading and visuospatial tasks) as well as different input/output modes as in *visuoperceptual* vs. *visuomotor* line bisection. Moreover, improvements were also obtained in a highly relevant task for daily living, i.e. paragraph reading. The fact that omissions (space based errors) could be reduced significantly whereas the less frequent substitutions were not affected by OKS treatment shows that the therapeutic effects are quite specific and cannot be explained by unspecific effects (i.e. arousal, test repetition).

Furthermore, leftsided omissions in cancellation were considerably reduced. The reason for the non-significant change of rightsided (ipsilesional omissions) in the OKS group lies in the simple fact that three of the five neglect patients showed only very rarely omissions on the right side of the test sheet and therefore could not improve further on this side after treatment (due to a ceiling effect).

With respect to line bisection, improvements were obtained for visuomotor *and* visuoperceptual line bisection tests indicating that the therapeutic effect transferred from perceptual tasks to those that require overt motor responses. Interestingly, OKS positively affected the visual size distortion in all three patients who showed such perceptual distortions before therapy. This result fits neatly to the positive but *transient* modulatory effect of leftsided OKS on visual size distortions in neglect reported recently by us [34]. It contrasts with the finding, that neck muscle vibration has neither a transient ("on-line") [34], nor a permanent effect on line bisection [35].

Despite the clearcut results reported here with OKS therapy some methodological caveats have to be kept in mind. First, our samples were relatively small and matched. Instead of a randomized allocation of subjects to one of the two treatments – which is feasible in studies with larger samples ($n > 25$) – the small sample size necessitated an individual matching of patients in the two treatment groups according to clinical and demographic variables. This was done to achieve relatively homogenous subgroups with respect to clinical variables and neglect severity. Clearly, this induces a risk of a selection bias [21], although we tried to parallel both samples as far as possible. Subsequent studies using OKS as neglect therapy should adopt a randomized control group design based on larger samples (see Lincoln and Bowen, this volume, for a detailed discussion of these aspects [21].

4.2. Comparison of OKS with other neglect treatments

When comparing the effects of the present study with other neglect treatments there are accordances as well as divergencies. OKS has similar therapeutic effects on visual neglect as attentional training [28], prism adaptation [7,8,32] and neck muscle vibration [11]. Nevertheless, few studies have so far *directly* compared the efficiency of these novel techniques with another *specific* neglect treatment, i.e. conventional VST. Most often, a novel treatment has been compared with an unspecific therapy or with a "no-treatment-group" receiving what is called "standard occupational and physiotherapy". Such a strategy clearly favours the more specific neglect treatment. The present study indicates that neglect therapy based on repetitive sensory stimulation is more effective than VST, although the latter is at least partially effective, too [1]. However, the effects of these "bottom-up" therapeutic techniques seem to be superior to those obtained with "top-down" compensatory strategies such as VST, or reach similar improvements in a considerably shorter time period. However, there are also limitations of these new "bottom-up"-techniques. Neither neck-vibration [35], nor OKS (present study), nor prism adaptation [6] seem to affect object-centered neglect phenomena, i.e. substitution errors in paragraph reading. Although these errors constituted only 3% of all reading errors in our patients other treatment approaches have to be developed for neglect patients with pronounced object-centered neglect of this type. Furthermore, the lack of OKS-treatment impact on object-centered neglect nicely illustrates the dissociability of space- and object-related attentional mechanisms.

4.3. What is the crucial effect of OKS therapy?

With respect to the putative mechanism of OKS in neglect therapy two hypotheses may be advocated, which are also compatible with each other. First, OKS or coherent background motion with slower velocities (even with small stimulus displays) may facilitate the directing of attention towards neglected regions of space [22]. This improved attention allocation leads to subsequent improvements in all visual neglect tasks requiring systematic leftward exploration, as in cancellation, reading, size comparisons or line bisection. This view is corroborated by the observation that forcing the patients' attention to the contralesional side produces a change in the degree of size distortion in patients with visual neglect [5]. A recent optokinetic treatment study [36] clearly corroborates this hypothesis. In this study, Sturm, Thimm and Fink found significant improvements in behavioural neglect tasks, including a visual attention test, after 3 weeks of optokinetic stimulation in seven patients with visual neglect, using the same device and test stimuli as we used in the present study (EYEMOVE). Moreover, they obtained evidence of a significant re-activation in posterior cortical regions (including angular gyrus, temporo-occipital areas, precuneus and posterior cingulate gyrus [36], induced by

Table 2
The mean improvement in performance (in %) after treatment (OKS = optokinetic stimulation versus visual scanning training = VST) as compared to averaged pre-treatment baseline values is indicated. Furthermore, we computed the mean change in performance at the follow-up investigation as compared to the averaged pre-treatment-baseline values as a measure of the stability of treatment effects (stability). Note, that the averaged improvements are higher for all test variables after optokinetic treatment, and that there similar values for stability and improvement in this group indicating stability of the improvements achieved during treatment. In contrast, the improvements in the visual scanning group were considerably smaller. −indicates deterioration, +indicates improvement

	Improvement	Improvement	Stability	Stability
Test Variable	OKS	VST	OKS	VST
Cancellation, omissions left side	+65.0	+23.0	+65.0	+13.7
Line Bisection Perceptual	+95.8	+27.7	+100	+33.3
Line Bisection Manual	+100	00	+100	00
Size Distortion	+50.0	+3.7	+45.0	+3.7
Reading, omissions	+21.7	+5.3	+17.4	+13.6
Mean (all tests)	+66.5	+11.9	+65.5	+12.9

OKS. In contrast to our study, the improvements remained only partially stable at the follow-up investigation 4 weeks after cessation of the neglect treatment in their patients. While the question of long-term stability of optokinetic neglect therapy clearly requires further in-depth-studies with longer follow-up-periods (i.e. 2–6 months) the fMRI-results of Sturm et al. [36] corroborate our earlier hypothesis [18] according to which repetitive optokinetic stimulation re-activates many of those cortical regions activated by the same stimulation in healthy subjects. These regions include those posterior cortical regions identified by Sturm et al. [36], as well as subcortical regions like the basal ganglia and the thalamus. More precisely, leftward optokinetic stimulation might *initially* activate the undamaged left hemisphere – as suggested recently [5] and *consecutively* via callosal fibers the damaged right hemisphere in patients with left neglect.

Another hypothesis which is well compatible with the scenario outlined above is that OKS facilitates the generation of a more accurate egocentric space representation by providing directional, visual motion input to this disturbed spatial representation in neglect patients. Since the visual motion system remains largely intact even after large cortical lesions [33], most of this system remains functional in neglect. In accordance with this hypothesis multiple activation sites in the lesioned and intact hemisphere were found with full-field OKS in an imaging study of hemianopic subjects without neglect [2]. Thus, global directional motion – even in a blind hemifield – might constitute a strong modulatory input to the visual motion system in the dorsal visual stream, thereby influencing spatial attention and perception in patients. Another interesting variable which has been completely neglected so far is the potential role of smooth pursuit eye movements which are elicited when following moving visual stimuli during OKS. Interestingly, Gur and Ron [9] were able to show a significant improvement in functional visual tasks after a feedback-based training of smooth pursuit eye movements in patients with closed head trauma, but without neglect. A recent functional imaging study with healthy subjects showed that smooth pursuit eye-movements as well as optokinetic nystagmus activate a largely overlapping neural network including the visual cortex, human area MT, the frontal and supplementary eye fields, parietal cortex and cerebellar regions of both hemispheres [20]. We hypothesized recently [18] that the partial *re*-activation of some of these regions can be induced by repetitive optokinetic stimulation in neglect patients and might constitute the physiological-anatomic correlate of the improvements seen in behavioural neglect tests in these patients. Indeed, this hypothesis was largely confirmed recently [36], as argued above. Furthermore, Sturm et al. [36] results strongly suggest that the strict dichotomy between neglect treatments based on attention training and neglect treatments based on sensory stimulation manoeuvers may be unnecessary and contraproductive since both types of treatment may lead to behaviourally equivalent improvements, although the physiological-anatomic mechanisms leading to these improvements may be quite different. We therefore believe that it is more fruitful for future research to combine different treatment approaches and evaluate whether this combination evokes greater improvements on the behavioural level.

Our positive results of OKS treatment in neglect are at variance with a recent study [26] using an individually adapted form of optokinetic stimulation in neglect patients who did not benefit significantly from this add-on-treatment which was given in addition to conventional scanning training. The reasons for these discrepant results are not clear at the moment. Future studies, using eye movement recording devices, will have to pinpoint precisely the crucial therapeutic mechanism(s), and evaluate whether OKS therapy has also beneficial therapeutic effects on functional measures, activities of daily living, on the unawareness and finally on *nonvisual* neglect. As many patients with visual neglect also show auditory [25] and tactile neglect [12] the aspect of crossmodal therapeutic efficiency deserves more attention in future studies. Both neck vibration [35] and prism adaptation [23] have crossmodal effects on tactile neglect which are not obtained with VST training [35]. In summary, the display of contralesionally moving visual stimuli via conventional PC technology provides an easy-to-use and effective therapeutic technique for patients with visuospatial neglect. In the future, randomized treatment studies will have to elucidate the precise mechanisms of action and evaluate possible crossmodal (haptic, auditory, representational) therapeutic effects of this method on multimodal neglect.

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