THE USE OF OPTOKINETIC STIMULATION IN REHABILITATION OF THE HEMINEGLECT DISORDER

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ABSTRACT

The aim of this study was to investigate whether it is possible to strengthen the rehabilitation of spatial hemineglect by combining standard training for spatial scanning with optokinetic stimulation. A simple randomized design was used: one group of neglect patients was treated with a combination of the two techniques, and a second group received only the standard treatment. Both treatments were given for six consecutive weeks and produced significant improvements. However, addition of the optokinetic stimulation did not improve the patients' performance. Also, none of the independent variables (i.e., presence/absence of hemianopia) predicted the positive effect occasionally observed in individual patients.

Key words: neglect, rehabilitation, optokinetic stimulation

INTRODUCTION

Patients with right cerebral hemisphere lesions often show a reduced tendency to respond to stimuli and to search actively for them in the contralateral part of space (Bisiach, 1999). This condition, described as hemineglect, greatly affects patients’ daily activities. For example, patients affected by hemineglect have considerable difficulty in dressing, eating, reading, etc. Hemineglect is also associated with reduced effectiveness of motor rehabilitation (Denes et al., 1982). The disorder affects about half of all right brain damaged patients (Gainotti, 1968). Some of these patients experience spontaneous recovery within the first weeks after onset (Hier et al., 1983). However, when observed at a chronic stage (i.e., after two months) spontaneous recovery is greatly reduced and the symptomatology can only be modified by rehabilitative intervention (Zoccolotti et al., 1989). Attempts to improve hemineglect were started about 40 years ago (Lawson, 1962). However, the effectiveness of the proposed training is still under debate.

The main issue is how much the improvement observed after specific training can generalize to everyday situations. Gouvier et al. (1987), Wagenaar et al. (1992), Robertson et al. (1990) and Hanlon et al. (1992) were unable to provide evidence that the positive effects of specific training extend to any condition outside of the therapeutic setting.

Other techniques have been more successful. An early approach that focused on training for visual scanning (Diller et al., 1974; Diller and Weinberg, 1977) was subsequently systematized and expanded by Pizzamiglio et al. (1992). The training procedures used in this approach produced substantial improvement in patients with neglect. Moreover, the improvement generalized to a variety of everyday living situations involving spatial exploration. A follow-up study showed that the beneficial effects of the training were stable over time (retest from 6 to 12 months after training). The above results were confirmed in a second study using a simple randomized design (Antonucci et al., 1995). The same procedure also produced functional improvement in motor recovery (Paolucci et al., 1996).

The apparent discrepancy between poor and good functional improvement of deficits has been tentatively interpreted as partly associated with the length of rehabilitation. In all studies reporting negative results, training lasted only a few days. On the other hand, in a second group of studies, all reporting positive results, training lasted from four (Weinberg et al., 1977) to eight consecutive weeks (Pizzamiglio et al., 1992; Antonucci et al., 1995; Paolucci et al., 1996).

In the present study, we used the rehabilitative procedure described by Pizzamiglio et al. (1992) as basic training for patients with hemineglect. In the past 15 years, several forms of sensory stimulation have proven effective in temporarily eliminating or reducing hemispatial disorders in neglect patients. Rubens (1985) described the prototypical stimulation. An injection of ice water in the outer ear canal of neglect patients produced vestibular stimulation with two main consequences: a) nystagmus with a slow phase toward the left side; b) reduction of neglect disorders on the left side of space. The improvement in space exploration (i.e., reading sentences and performing a cancellation task) lasted from 5 to 10 min. Then, the patients returned to their previous impairment.

A second approach consisted of optokinetic stimulation (Pizzamiglio et al., 1990). When
neglect patients performed a line bisection task while random dots moved leftward on the background at a critical speed, an optokinetic nystagmus could be observed with a slow phase moving leftward and a reduction of the rightward bias in bisecting a line. In this case, the improvement of space exploration was maintained throughout the stimulation and quickly disappeared as soon as the background movement stopped. Subsequent stimulation included the following: lengthening of neck muscles by rotating the head over the trunk, muscle vibration (Karnath et al., 1993) or TENS (transcutaneous electrical neuronal stimulation) (Vallar et al., 1995). A large number of transient effects were described for these forms of stimulation, including improvement of space exploration, anosognosis, visual imagery and sensory and motor functions.

All of these sensory inputs (vestibular, visual and somatosensory/proproprioeptive) apparently contribute to the dynamic balance of egocentric representations of personal and extrapersonal space. Unilateral lesions in neglect patients produce a distortion of these representations toward the side of the lesion. Lateralized stimulation of one of the sensory channels can counterbalance the distortion, thus reducing the bias and causing the patient to fail to perceive contralesional stimuli and organize motor responses to them (Pizzamiglio et al., 1996). This view implies the existence of a neural substrate that integrates this sensory information into non-primary representations of space. Relative to this point, neurons responding not only to vestibular but also to optokinetic and proprioceptive/somatosensory inputs have been found in the parieto-insular vestibular areas (Grusser et al., 1992).

All researchers working in this area have stressed the potential importance of these stimulation techniques for use in the rehabilitation of visuospatial hemineglect. However, no attempts have been made to test whether systematic stimulation with any of the above techniques has a long lasting effect on patients’ performances or results in a generalization of the changes to everyday living situations. An empirical response to these questions is necessary to transform interesting experimental findings into a systematic procedure for the rehabilitation of neglect disorders.

Starting from the above considerations, the aim of the present study was to try to strengthen and accelerate the rehabilitation of hemineglect by combining a standard training for spatial scanning with a form of sensory stimulation, namely, optokinetic (OK) stimulation.

An injection of ice water into the outer ear has practical as well as other limitations in a therapeutic setting since it involves several sessions, each lasting an hour or more. The other conditions (vibration or TENS stimulation of the neck muscles or optokinetic stimulation) can be easily and comfortably administered while the patient is performing a number of tasks. From previous studies (Pizzamiglio et al., 1990; Karnath, 1996), it was concluded that the effect of optokinetic stimulation is greater and more easily observed in a large number of patients.

Previous nonsystematic use of OK stimulation in our hospital provided some preliminary and anecdotal evidence of its potential advantage in the treatment of neglect patients (Antonucci et al., 1992). Compared to a non stimulation condition, space exploration under OK stimulation reduced the rightward bias while patients were performing a visual search task. However, this advantage was evident in very severe neglect patients and in the early phases of their training. When the disorder decreased in intensity, the effectiveness of the combined training seemed to disappear.

Since the above observations are primarily based on comparisons of trials with or without OK stimulation in the same therapeutic session, no strong claims can be made.

The purpose of the present study was to examine the potential effectiveness of combining a standard rehabilitative procedure with optokinetic stimulation.

The study paradigm was a simple randomized design, comparing two groups of patients with right hemisphere lesions and hemispatial neglect: one group (A) was treated with a combination of the two techniques, and another group (B) received only the standard treatment.

The dependent variables were the following: 1) a quantitative assessment of neglect disorders before and after treatment A or B; 2) a semiquantitative and functional evaluation of the patients’ improvement in everyday activities and in functional independence.

An attempt was also made to qualify which patients (in terms of severity and type of disorder) were eligible for this combined treatment.

The expected results were either acceleration of improvement during the combined training or an extension of improvement to behaviors that tend to be less susceptible to standard treatment (i.e., personal neglect).

**METHODS**

**Subjects**

Subjects included 22 right hemisphere brain damaged patients with hemispatial neglect, consecutively identified in the three participating hospitals (Italian, Dutch and Finnish). The patients had to meet the following criteria: vascular etiology (CVA); age below 75; first stroke; single lesion; no sign of mental deterioration or history of previous psychiatric disorders; one to four months from stroke onset.
Assignment to group A or B was carried out as follows. In each hospital, the first patient was assigned to group A, according to date of hospitalization, and the next patient to group B. A total of 140 patients were scored in the three countries to find the 22 selected for the present study. The patients’ clinical and demographic characteristics are shown in Table I.

Groups A and B did not differ for age ($t = .50$, $p < .62$), education ($t = .71$, $p < .49$) or time elapsed since injury ($t = 1.20$, $p < .24$).

Tests

The standard battery for neglect includes four tests:

(1) Line Cancellation (Albert, 1972)

The patient’s task is to cross out 21 slanted lines (2.5 cm) printed on a 42 × 30 cm sheet of paper, 11 on the left side and 10 on the right side. The score is the number of omissions on the left and right sides of the sheet. Healthy subjects make no errors on this test.

(2) Letter Cancellation (Diller and Weinberg, 1977)

The patient’s task is to cross out 104 uppercase “H’s” (4 mm high), printed in six horizontal lines on a 42 × 30 cm sheet of paper, 53 on the left side and 51 on the right side. The targets are interspersed among 208 distracters (letters). The score is the number of omissions on the left and right sides of the sheet. The maximum number of omission errors in healthy subjects is four; the maximum difference between errors on the left and on the right side is two.

(3) Reading

Patients are asked to read six sentences aloud [mean length 8.3 words (32.8 letters), range 5-11 words (21.42 letters)], printed uppercase in the center of a 29.7 × 21 cm sheet of paper. In three sentences, the letters are 5 mm high, in three, 3 mm high. The score is the number of incorrectly read sentences. Healthy subjects and right brain damaged patients without hemineglect make no errors. Patients with neglect make omission errors, substitution errors, or both, in the left half of the sentence (Pizzamiglio et al., 1989).

(4) Wundt-Jastrow Area Illusion Test (Massironi et al., 1988)

In this test, each stimulus includes two black fans with the same shape and surface. Phenomenally, one fan appears longer than the other. This illusory effect can be produced either by the left or by the right side of the fans. For each stimulus, the patient is required to judge which fan is longer. Forty stimuli (20 with a left-sided and 20 with a right-sided illusory effect) are presented in fixed random order. Normal subjects perceive the expected illusory effect in all trials. Patients with left spatial hemineglect fail to perceive the illusory effect when the fans are oriented toward the left. Conversely, the expected effect is present when the illusion is produced by the right side of the fans.

Patients were considered to have neglect when their scores were below the cutoff in three out of four tests (Antonucci et al., 1995).

Additional tests included:

– Test of personal neglect (Zoccolotti and Judica, 1991)

In this test, patients have to demonstrate how to comb their hair, shave themselves (men), powder their faces (women) and wear (put on) eyeglasses (range: 0-9).

– Line bisection test, from the BIT (Wilson et al., 1987).

To evaluate everyday living disorders, the

<table>
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<tr>
<th>Subject</th>
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<th>Age</th>
<th>Education (years)</th>
<th>Interval (months)</th>
<th>Lesion</th>
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<td>10. OK –</td>
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P = parietal; T = temporal; O = occipital; F = frontal; IC = internal capsula.
Semi-structured Scale for the Functional Evaluation of extrapersonal neglect (Zoccolotti et al., 1992) was used. In this test, the patient is required to perform concrete actions of everyday living that have spatial components, e.g., to serve tea with real cups, teapot, sugar, etc. to four people sitting around a table (the patient is one of the four; range: 0-15).

**Training**

A) Specific Training for Neglect

The training for neglect has been described in detail elsewhere (Pizzamiglio et al., 1992). Briefly, it consists of four different procedures:

1. **Visual-scanning training**
   
   The patient has to detect digits appearing in sequence on a large screen (2.20 × 1.50 m) in 48 different positions. In the early sessions, the digits are presented in a linear sequence and the patient has to press a key and read each stimulus aloud as quickly as possible. As the patients’ scanning abilities improve, nonlinear and less predictable presentation sequences are used. Both response time and number of omissions are recorded.

2. **Reading and copying training**
   
   Patients are presented with newspaper headlines and handwritten sentences, which they are required to read and copy. The words and sentences are of different degrees of linguistic and/or perceptual complexity (i.e., length of sentences, size of written material, etc.).

3. **Copying of line drawings on a dot matrix**
   
   In this procedure, drawings of solid lines connecting dots are presented on the left side; the patients are required to copy them on a matrix on their right side. The number of dots (from 4 to 20) and lines are progressively increased.

4. **Figure description**
   
   Black and white pictures are shown to the patient, who must describe them in detail. Increasing difficulty is represented by more elements to be described in the scene.

In this study, verbal and visual cues were provided during the early training stages in all procedures and then progressively reduced when the patient’s exploration ability increased. Throughout the training, the level of difficulty was consistently adjusted to the individual patient’s performance. The training was given five times a week; each session lasted approximately one hour. In each hospital, the same therapist treated all patients.

B) Optokinetic stimulation (OK)

B1. Critical speed of the moving background was determined. The patient looked at the center of a large screen (2.20 × 1.50 m) where a set of random black dots moved from right to left at different speeds (from 10° to 60°/sec); a mirror placed in front of one eye allowed for the evaluation of nystagmus. The speed that produced the greatest amount of nystagmus/min was used in the training sessions; the identified critical speed was used throughout the treatment.

B2. The visual-scanning training described in section A was administered with a leftward moving background at the critical speed for each patient. The combined training was administered for 30 min in each session, and was followed by the other parts of the training in normal vision.

Group A received the specific training for neglect and the optokinetic stimulation; group B received only the specific training.

Both treatments consisted of 30 consecutive sessions, 5 per week, each lasting one hour.

**Pre-Post Training Test**

The assessments indicated in the Test section were made immediately before and after treatments (A or B).

**Assessment during Treatment**

1) Effect of optokinetic stimulation (OK).
   
   Baseline (without OK): at the end of each week of treatment (6 times), the patient completed one sequence of 48 digits appearing in a random sequence and in a random position on the screen. The number of correct identifications and the time required to identify each digit was recorded. A similar sequence of digits was repeated with the OK stimulus on the background. The difference between the OK stimulation and the baseline indicated the effectiveness of the stimulation at that particular stage of the treatment.

2) The battery for neglect and the semi-structured scale were administered after 15 days of treatment.

Figure 1 summarizes the testing sequence during the experimental observation.

**Neurological Information**

A standardized neurological examination was included in the initial examination. A functional evaluation of impairment was made using the Barthel Index (Mahoney and Barthel, 1965) at the first evaluation.

**Neuroimaging.** A CT scan or MRI evaluation was available for all patients.

**Procedure**

A neuropsychological evaluation of the patients was made pre-, mid- and post-treatment.

The Barthel Index was administered pre- and post-treatment by a psychologist and a neurologist, respectively; both were unaware of the patient’s assignment to one treatment group or the other.
RESULTS

The results will be described in two sections.
a) Group effects of treatment with and without OK.
b) Measures that predict rehabilitative outcome.

a) Group effects.

Severity of neglect was compared pre-, mid- and post- treatment in the two groups of patients, i.e., the group that received OK stimulation and the group that did not.

The scores on the four screening tests (line and letter cancellation, Wundt-Jastrow Illusion and reading) were transformed into z scores, with reference to a large sample of patients (140) previously studied (Pizzamiglio et al., 1989); the average z scores obtained before and after treatment were the dependent variable. An analysis of variance group by pre- mid- post-treatment (repeated measures) showed a significant main effect of treatment \([F (2, 40) = 23.29; p < .000]\), but no group effect or interaction. A post-hoc comparison showed a significant improvement between pre/mid and pre/post \((p < .0001\) in both cases, Duncan test), but no significant changes between mid/post- treatment \((p = .58\), Duncan test) (see Figure 2).

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Fig. 1 – Evaluation sequence for the entire experimental treatment in both groups of patients.

OKe = OK effect: difference between baseline and OK stimulation using a sequence of digits presented in random order in 48 different positions on the screen; NT (1,2,3) = complete test battery for Neglect; FS = Functional Scales for Neglect; NE = Standard Neurological Examination + neuroimaging; B.I. = Barthel Index.

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Fig. 2 – Severity of neglect (average z scores of the screening tests) pre-, mid- and post-treatment in the two groups (with and without OK stimulation).
A second analysis was performed using the scores of the functional evaluation of extrapersonal neglect as dependent variable. The group by pre- mid- post-treatment again showed a significant main effect of treatment \([F (2, 40) = 30.93; p < .000]\), but no group or interaction effect. The Duncan test showed a significant difference between all conditions \((p < .001 \text{ for pre/mid- and pre/post-treatment}; \ p < .05 \text{ for mid/post- treatment})\).

The score of the Scale for Personal Neglect was submitted to a similar analysis group by pre- mid- post-treatment. No main effect reached significance \([\text{group effect: } F (1, 20) = 1.01, \text{ ns}; \text{treatment effect: } F (2, 40) = 2.03, \text{ ns}]\). The interaction showed a trend, but the effect did not reach significance \([F (2, 40) = 2.68; \ p = .08]\).

Overall, at least two of the three analyses showed that the treatment produced a significant change but that the improvement shown by the patients after treatment was not influenced by the use of OK stimulation.

Finally the intercorrelations between the amount of change (pre-, mid-, post- treatment) and the measures of personal and extrapersonal neglect were separately computed for the two groups (with and without OK stimulation). The correlations for the group with OK stimulation were non significant for personal \((r = .30, p = .37)\) and for extrapersonal neglect \((r = .37, p = .26)\); for the group without OK stimulation, they were significant for extrapersonal \((r = .60, p < .05)\) and non significant for personal neglect \((r = .27, p = .41)\). Similar to the results reported before, these data are congruent with previous observations, i.e., the treatment used in this study is more effective for extrapersonal neglect than for personal impairments (Pizzamiglio et al., 1992).

A final comment refers to the visual scanning procedure. Figure 3 describes the trend of the groups’ responses. The average number of omissions in both the sequence with (PRO) and without (PR) OK stimulation were used as dependent measure.

The figure shows the mean performance of each group for each of the seven assessments. The decrease in the number of omissions is clearly observable, but no differences emerged between the two groups.

b) Prediction of rehabilitative outcome

Since no group effect was found when optokinetic stimulation was added to the standard treatment, at the beginning of the treatment we tried to predict individual patients who would benefit from this combined procedure.

Three measures were used to quantify amount of improvement:

- the difference between the clinical evaluation of the degree of severity before and after treatment; a Likert 5-point scale of severity was used, with 5 indicating severe impairment and 1 mild impairment;
- the difference between the scores on the
Extrapersonal Neglect Scale administered before and after treatment;
the difference between the scores on the Personal Neglect Scale administered before and after treatment.

Three potential predictors were used:
– the Barthel Index, measured before treatment;
– the presence or absence of visual field defects on the contralesional side;
– the presence or absence of motor impairments before treatment.

Both measures of improvement and predictors were dichotomized (Table II).

The mean improvement (severity pre- post-treatment) on the scale for overall severity of neglect was .85: 22 patients were classified as above or below the mean group improvement. A similar dichotomization was performed for the Scales of Extrapersonal Neglect (mean = 4.32) and Personal Neglect (mean = .95).

The scores on the Barthel index were treated the same way (mean = 47.5). The presence or absence of visual field defects and motor impairments divided the patients into two groups.

The Chi² was used to test whether any of the three predictive variables could discriminate significantly between patients with good recovery and patients with poor recovery.

As can be seen, none of these predictions reached the significance level.

We also checked whether the patients who received the OK stimulation were represented differently in relation to the three predictive variables (no. of patients with OK+/– in relation to Barthel Index above/below mean of total group).

Table III reports the Chi² of these comparisons, again showing that none of these variables was responsible for the outcome of the two treatments.

**Discussion**

The first aim of the present study was to test the effectiveness of optokinetic stimulation given together with a standard rehabilitative procedure for the recovery of neglect.

The results showed that a specific rehabilitative treatment given for six consecutive weeks is likely to produce significant improvements when quantitative measures of neglect are compared as well as a functional evaluation of the patients before and after treatment. Since the study design was focused on a comparison between two treatment conditions, it cannot be ruled out that the observed changes were due to spontaneous recovery.

We can simply say that the present data are in
agreement with findings of previous controlled studies on the effectiveness of the training used (Antonucci et al., 1995). However, the addition of OK stimulation for the same amount of treatment did not produce any additional improvement in the patients’ performances, whether quantitative or functional measures were used.

The negative results cannot be easily explained by the methodological characteristics of the study. One explanation may be that the whole group of patients was composed of three different subgroups observed in three different countries. Due to the different policies of the national health systems, the average severity of the neglect patients in the Italian subgroup was greater than that of the Dutch and Finnish groups. Perhaps the negative results are related to the mild degree of impairment in the overall group of patients. Contrary to this hypothesis, the data showed substantial independence of the severity of the initial impairment from the outcomes in either group with or without OK stimulation.

A second explanation concerns the development of the impairments during the different treatment stages. Previous clinical observations (Antonucci et al., 1992) showed that some individual patients improved remarkably when the searching task was performed with OK stimulation. However, this improvement, i.e., the difference between explorative performances with and without OK, was quite visible in the early treatment stages, but tended to disappear in later sessions. The analyses performed on the present data do not support this explanation since no group by treatment interaction was found for any of the variables used.

In spite of these negative results, clinical observation suggests that individual patients benefit strongly, at least for a few sessions of OK stimulation. One such patient in the present group has been described elsewhere (Boelen et al., 2001).

From a clinical standpoint, it is important to predict whether an individual patient will be susceptible to the positive effect of OK stimulation. Among the potential predictors, it seems that visual field defects are particularly important since they reduce the size of the stimulation of the moving background. However, none of the independent variables used, including the presence/absence of hemianopsia, could predict the effect of the stimulation.

Finally, it can be speculated that the speed of the OK stimuli was either too high or too low. In the present study, the speed of the moving background was adjusted individually, and the speed that produced the highest nystagmus per min. was used in the treatment sessions. Under these conditions, all patients included in the study showed a significant effect in performing a line bisection task.

In spite of this transient sensitivity to OK stimulation, no significant effect was observed in the recovery of spatial exploration. Other studies have demonstrated transient effects at a much lower speed of background movement (Mattingley et al., 1994; Kerkhoff, 2000; Kerkhoff et al., 1999). Therefore, perhaps the use of low speed movement is more effective.

A general comment is needed to underline a paradoxical phenomenon in neuropsychology. Different from other cognitive disorders following a brain lesion (such as language or memory deficits), a great variety of perceptual, motor, and imaginative manifestations of hemispatial neglect can be transiently and substantially reduced for a short period of time by a number of lateralized sensory manipulations (caloric vestibular, optokinetic, cutaneous electrical stimulation and lengthening the neck muscles by rotating the head over the trunk). In contrast, the systematic use of such stimuli in the context of training for neglect, even when applied for a long time, does not produce any relevant advantage in the recovery of spatial disorders. A previous attempt, consisting of the prolonged use of TENS stimulation of the neck muscles in four neglect patients (Pizzamiglio et al., 1996), gave unconvincing results, similar to the present ones.

It must be concluded that neglect undergoes positive recovery, which extends to activities of daily living, as documented by improvement on the functional scales. These positive changes observed in patients are most likely due to a complete and slow reorganization of the spatial experience induced by the specific neglect training program (Pizzamiglio et al., 1992; Antonucci et al., 1995; Paolucci et al., 1996).

On the other hand, different lateralized forms of stimulation, such as TENS and OK, are not easily integrated with the perceived and organized responses activated by the specific training. The latter procedure involves an active reorganization of spatial processing, while passive stimulation does not seem to help consolidate the compensatory neural connections within the residual intact brain.

The negative rehabilitative results discussed so far do not mean that other peripheral manipulations are not useful in the treatment of neglect. Two examples can be mentioned.

“Contralesional limb activation” while performing a variety of tasks was used by Robertson et al. (1998). This manipulation had a positive effect on spatial performances in neglect patients. The effectiveness of this technique has been documented in a series of single cases as well as in group studies (see a recent review by Manly, 2002). However, two studies reported either great variability in patients’ responses to this technique (Brunila et al., 2002) or a small number of patients who showed positive results (Cubelli et al., 1999).

In a second approach, introduced by Rossetti et al. (1998), the patient wears prismatic lenses that produce a rightward distortion of space. After a short period of adaptation, during which the patient
is engaged in a pointing task, a significant leftward deviation in pointing can be observed. Frassinetti et al. (2002) used this method for 20 sessions with chronic neglect patients. They observed significant improvement in most patients, which generalized from experimental manipulations to everyday living improvements.

It may be that both of these procedures, i.e., prismatic lenses and limb activation, require a sufficiently active response from the neglect patients, which is then responsible for the improvement in spatial processing. More systematic studies are necessary to convincingly verify the positive effects of such techniques in neglect rehabilitation.

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