Decrease of contralateral neglect by neck muscle vibration and spatial orientation of trunk midline

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SUMMARY

Three patients with a right hemisphere lesion and marked left-sided neglect without visual field defects were asked to detect and identify stimuli which were tachistoscopically presented in the left or right visual half-field. Neglect of stimuli presented in the contralateral left visual field, which was observed when the patient's body was in a normal upright position with trunk, head and gaze oriented straight ahead to the middle of the projection screen, could be reduced by vibrating the left posterior neck muscles as well as by turning the trunk 15° to the left. In contrast, unspecific stimulation on the left side of the patient's body, produced by vibrating the left hand muscles or the proprioceptive signal induced by turning the head 15° to the left, had no compensatory effects. The results showed that the afferent information about real lengthening of the left posterior neck muscles (produced by turning the trunk) as apparent lengthening of these muscles (produced by their vibration), leads to a remission of contralateral neglect. Thus, the proprioceptive input from the neck muscles, i.e. the head-on-trunk signal, appears to influence the extension of the neglected part of space in patients with neglect. The signal seems to contribute substantially to the neural generation of the egocentric frame of reference that allows the determination of body position with respect to visual space. We hypothesize that the reduction of neglect by vibration of the contralateral posterior neck muscles is based on a shift of the subjective spatial localization of the sagittal midplane in the contralateral direction and a corresponding alteration of the egocentric coordinate system necessary for visuomotor coordination and exploration of space.

INTRODUCTION

In human subjects, vibration of muscles or muscle tendons produces kinaesthetic illusions (Goodwin et al., 1972; McCloskey, 1973). The illusion involves the perception of a constant movement as well as a spatial displacement of limb positions. The illusions can be explained as the (false) central interpretation of the altered proprioceptive input from the periphery. The discharge induced by the vibration is coded as lengthening of the vibrated muscles. Vibration-induced illusions of limb motion can affect the somatosensory representation of the whole body and the apparent position and
configuration of the body in relation to the environment. Depending on the position of the vibrated limbs in relation to the subject’s head and trunk, it is possible to generate systematic perceptual distortions of the body and changes in the apparent orientation of the body (Lackner, 1988). It has become apparent that proprioceptive input from the muscle spindles provides information not only for the creation of a subjective map of the body, but also for the orientation of this map in the external world (Matthews, 1988).

Lackner and Levine (1979) as well as Biguer et al. (1988) reported on the influence of proprioceptive signals from the neck muscles in the elaboration of egocentric coordinates of visual space. Biguer et al. (1988) investigated normal subjects sitting with their head and body oriented straight ahead towards a central stationary spot of red light. The target was presented with no visual background in a dark room. During the vibration of the left posterior neck muscles the subjects reported an apparent motion and displacement of the stationary visual target towards the right. When requested to point to the target, the subjects performed a consistent error in pointing which was in the same direction as the illusory displacement. Moreover, when the target had to be moved until the subjects perceived it as lying in their subjective midline the target was usually located to the left of the physical midline. These findings indicate that the vibration-induced afferent head-on-trunk signal, namely the false information that the left posterior neck muscles have lengthened, resulted in a centrally computed displacement of the egocentric midline of the body-centred representation of visual space.

Taylor and McCloskey (1991) were able to replicate the observations of Biguer et al. (1988). In addition, they showed that vibration of the left posterior neck muscles can alter the perceived position of the head in normal subjects. This kinaesthetic illusion was in the same direction as the visual illusion of target movement, but of smaller magnitude.

In search of the egocentric frame of reference determining the neglected and the attended side of space in neglect patients, Karnath et al. (1991) found evidence that the spatial trunk orientation, rather than retinal or head-centred coordinates, constitutes the physical anchor for calculating the internal coordinate frame, which represents body position with respect to visual space.

Comparing saccadic reaction times to stimuli in the left visual field and the right visual field, the authors measured prolonged saccadic reaction times to stimuli presented in the contralesional left visual field when the midlines of head, trunk and visual field of their patients were parallel and oriented straight towards the middle of the projection screen. Saccadic reaction times were, however, found to be in the normal range when the patient’s trunk was turned to the left by 15° with the head still facing the projection screen. Under this head/trunk position, both left and right visual field stimuli lay on the right, ipsilesional side of the trunk midline. Variation of head orientation alone showed no effect. Apparently, with the trunk turned, the stimuli appeared on the attended ipsilesional side and the patients were able to respond with normal latencies.

The relative deviation of the trunk midline to the left from the straight ahead head/eye orientation led to the compensation of increased values of left-sided saccadic reaction times. Turning of the trunk under this test condition led to a lengthening of the left posterior neck muscles. For this reason, the authors speculated that the altered head-on-trunk signal, induced by turning the trunk to the left (together with the signal of
the eye-in-head position), might account for the compensatory effect of turning the trunk in their patients with neglect. If this hypothesis is correct, then it should be possible to induce a remission of hemineglect not only by turning the trunk to the contralateral side but also by vibrating the contralateral posterior neck muscles. Both conditions induce the same afferent head-on-trunk signal. Whereas in the first case the proprioceptive input of the neck muscles is elicited by a real lengthening of the muscles, in the second case it is provoked by the false interpretation of the afferent signal that these muscles have lengthened.

**METHODS**

**Patients**

All patients and control subjects gave informed consent to participate in this study.

**Patient A.D.** This 84-year-old female patient sustained an occlusion of the right middle cerebral artery. The computerized tomography (CT) scan performed 3 weeks after the stroke revealed an extensive lesion of the right hemisphere. The hypodense areas extended from the frontal lobe to the parieto-occipital junction. The patient suffered from a mild left hemiparesis. Anosognosia for the left-sided hemiparesis was observed. No visual field defect was found by Goldmann perimetry.

Neuropsychological examination of A.D., 51 days after the stroke, revealed a marked left-sided hemineglect. Clinical confrontation testing with visual, auditory and somaesthetic stimuli showed a normal reaction to unilaterally presented right or left stimuli and no reaction to any of the left stimuli in all three modalities with bilateral presentation. A.D. omitted details on the left side when asked to copy a flower and displaced the mark to the right in line bisection. On the ward it was observed that the patient neglected the left half of the dishes. She only ate the food which was located on the right of her plates.

Neuropsychological examination of the patients with neglect also included the same task and stimuli as were used by Bisiach and Rusconi (1990). The patients were asked to compare two drawings of an object (a house, a pot of flowers and a glass) that were placed exactly one above the other on a sheet of DIN A4 paper. The drawings were identical except for a difference on the left side of the object (e.g. flames out of the window of one of the houses).

A.D. (tested 51 days after the stroke) was not able to detect the difference in the three pairs of stimuli. However, she found the difference at once when the mirror-reversed pictures, with the same difference now on the right side, were presented.

**Patient J.L.** This 69-year-old male patient suffered two strokes affecting the posterior branch territory of the right middle cerebral artery 3 years and 20 days before the present examination. The CT scan performed 3 days after the second stroke revealed a hypodense area which extended from the temporal lobe to the parieto-occipital junction. The patient suffered from a severe left hemiparesis. Goldmann perimetry showed a normal binocular visual field.

Neuropsychological examination of J.L., 20 days after the onset of hemiparesis, revealed a marked left-sided hemineglect. Clinical confrontation testing with visual, auditory and somaesthetic stimuli showed a normal reaction to unilaterally presented right or left stimuli and no reaction to any of the left stimuli in all three modalities with bilateral presentation. He omitted the whole left side when asked to copy a flower and failed to complete a clock-face on the same side. Tested with a letter cancellation task (Mesulam, 1985), the patient marked only six letters on the extreme right of the test sheet. On the ward, the patient frequently collided with objects positioned on his left.

We also examined J.L. (20 days after onset of hemiparesis) with the picture comparison task (Bisiach and Rusconi, 1990). The patient did not detect the left-sided difference in two of the pairs of stimuli. All three differences were found at once when the mirror-reversed pictures were presented.

**Patient M.B.** This 53-year-old male patient sustained an occlusion affecting the territory of the right middle cerebral artery. The CT scan taken 2 days after the stroke revealed a hypodense area including the right basal ganglia and extending into the frontal white matter. The patient had a severe left hemiparesis. No visual field defect was found by Goldmann perimetry.
Neuropsychological examination of M.B., 26 days after the stroke, showed a marked left-sided hemineglect. Clinical confrontation testing with visual, auditory, and somaesthetic stimuli yielded 80% correct detection of stimuli unilaterally presented on the right or left but only 10% correct responses to the left stimuli in all three modalities with bilateral presentation. The patient had difficulties in completing a clock-face on the left side and displaced the mark to the right in line bisection. On the cancellation task, the patient marked only the right third of the test sheet. The patient also complained of reading difficulties due to word omissions at the beginning of the lines.

When examining M.B. with the picture comparison task (26 days after the stroke), the patient had no difficulty detecting the differences on the left side.

Controls. Five patients with unilateral left brain-damage, aged from 44 to 61 years (median = 58 years), served as a control group. In three of the patients the lesions were due to an infarct affecting the territory of the left middle cerebral artery. The other two patients suffered from left temporal haemorrhage. None of the five patients showed any signs of hemineglect or visual defect. The time since the lesion ranged between 3 and 43 months (median = 9 months).

As an additional control group, 15 non-brain-damaged dermatological patients, aged from 30 to 60 years (median = 46 years), were examined.

Procedure

When tested with the clinical confrontation method, patients with neglect usually show normal detection of unilaterally presented stimuli on both sides and a neglect of contralateral stimuli with bilateral presentation. As described, this was also observed in A.D., J.L. and M.B. However, it has been demonstrated that the patient’s accuracy of processing unilaterally presented stimuli depends on the task difficulty (Karnath, 1988). The contrast between undisturbed processing of contralateral information under unilateral and impaired processing under bilateral presentation vanishes with the increase of task difficulty. By a reduction of stimulus exposure time to 10 ms, for example, the patient’s ability to name unilateral stimuli on the contralateral side of fixation decreases while the response to those on the right side still lies in the normal range.

Task difficulty was adjusted differentially for the three patients with neglect to elicit contralateral neglect under unilateral presentation of stimuli. J.L. and M.B. were given an identification task. The stimuli, which the patients were asked to name, were colour photographs of geometrical figures (rectangle, triangle, star, etc.). For construction of the figures, four different colours and eight different shapes were used (cf. Karnath, 1988). Stimuli were presented unilaterally in the subject’s left or right visual half-field. They were tachistoscopically back-projected onto a translucent screen in an area (4°x8.6°) beginning 4° left or right of a central fixation point, marked by a yellow light-emitting diode (LED). The stimuli were presented with an exposure time of 10 ms and were immediately followed by a random dot mask. For A.D., the identification task turned out to be too difficult. Therefore, this patient was asked to perform a simple detection task. Using the same experimental technique, she was asked to determine whether a white circle (4° of size on a black ground) was tachistoscopically presented to the right or left side of fixation (yellow LED). The stimuli were presented with an exposure time of 100 ms.

The geometric figures to be used as stimuli during visual half-field presentation were demonstrated in detail to the subjects, and correct naming was drilled with practice items. In both visual half-fields a maximum of 60 correct answers could be given under each of the six experimental conditions described below. Five blank field items were added in each condition and randomly presented together with the test stimuli (no subjects gave any false positive responses).

The following procedure was introduced in order to reduce the risk of deviations of gaze from the central fixation point (yellow LED) and to direct the subject’s attention towards that point before a stimulus was presented. Upon the initiation of each presentation the patient had to fixate on a red LED 8° above the central fixation point. By pressing a button the examiner triggered the continuation of the trial; a beep was sounded and after a random interval (between 250 and 750 ms) the central fixation point lit up. Thus, the subject was not able to predict the onset time of the fixation point necessitating a saccade from the red to the yellow LED. This saccade (8° of visual angle) was intended to direct the subject’s attention towards the central fixation point before each presentation of a stimulus. Respectively, it should prevent the patients with neglect from improving their perception of left visual field stimuli by overtly or covertly orienting their attention to the neglected left side before a stimulus was presented. The exposure of a stimulus followed 750 ms after the central fixation point lit up.
The possible influence that neck muscle vibration and spatial trunk-orientation might have on the patients' processing of stimuli in the visual half-fields was investigated in five different test conditions and one control condition. In each of the conditions the retinal projection of the stimuli was held constant by directing the subject's gaze towards the centrally presented fixation point before each presentation of a stimulus. Each subject was tested in the following order of conditions.

**Condition I.** In this 'baseline condition', the subjects sat with a normal upright body position 97 cm in front of the projection screen. Orientation of the head and trunk midline was aligned with the middle of the projection screen and the location of the fixation point.

**Condition II.** The trunk was turned 15° to the left while the head was facing straight ahead. This deviation of the trunk midline resulted in both the left visual field and right visual field stimuli being projected to the right side of the trunk (see Fig. 1).

**Condition III.** The trunk was turned 15° to the right while the head was facing straight ahead. This deviation of the trunk midline resulted in both the left visual field and right visual field stimuli being projected to the left side of the trunk (see Fig. 1).

**Condition IV.** The left posterior neck muscles were vibrated with a physiotherapy vibrator (100 Hz) while trunk and head were facing straight ahead.

**Condition V.** The right posterior neck muscles were vibrated (100 Hz) while trunk and head were facing straight ahead.

**Control condition.** This condition was added as control for the possibility that the expected decrease of contralateral neglect with vibration of the left posterior neck muscles and with turning of the trunk to the left side is simply caused by an arousal effect due to unspecific sensory or proprioceptive stimulation on that side. Therefore, it was planned to vibrate the muscles of the left hand of the patients as one control condition and to turn the head 15° to the left as another. Unfortunately, in two of the patients with neglect only one of these two manoeuvres could be carried out. Patient J.L. refused to continue with the examination, and A.D. left the hospital before the second control condition had been administered. Thus, in J.L. only the left hand muscles were vibrated (100 Hz), while his head and trunk were facing straight ahead. A.D. was tested with her head turned 15° to the left, while her gaze and trunk were facing straight ahead (cf. Karnath et al., 1991). M.B. was tested under both control conditions. First, as with J.L., the patient's left hand muscles were vibrated (100 Hz), while his head and trunk were facing straight ahead. Secondly, as with A.D., he turned his head 15° to the left, while his gaze and trunk were oriented straight ahead.

According to Matthews (1982) and Biguer et al. (1988), neck muscle vibration produces visual illusions only in darkness when no visual control and structured visual environment can be used. Therefore, during the different experimental conditions, the room was completely dark when the vibrator was used (conditions IV, V and control condition). For the convenience of the patient and the examiner under conditions I–III a dim light was on in the test room to avoid prolonged testing in complete darkness. This seemed to be
justified because it was known from the study of Karnath et al. (1991) that complete darkness is not a necessary condition to obtain an effect of trunk rotation on neglect.

For each subject the exact position of the tip of the vibrator on the left posterior neck muscles was individually adjusted in trying to achieve an illusion of apparent displacement of the fixation point (yellow LED) in the horizontal plane. If no illusion could be induced, vibration was applied below the left occiput just lateral to the spine.

RESULTS

Controls

The two control groups performed the detection of right and left visual field stimuli (conducted for comparison with A.D.) 100% correct in all five test conditions and the control condition.

The identification task was also completed with a high percentage of correct responses by both control groups (Table 1). Comparing the different conditions (Friedman test,

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<th>Side of presentation</th>
<th>Condition</th>
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<td>93.7</td>
<td>91.0</td>
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<td>(5.9)</td>
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<td>(6.4)</td>
<td>(4.2)</td>
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<tr>
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<td>Left visual field</td>
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<td>99.3</td>
<td>99.0</td>
<td>97.3</td>
<td>97.0</td>
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<td></td>
<td>Right visual field</td>
<td>95.7</td>
<td>98.3</td>
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Averaged percentage of correct naming responses in the identification task for left visual field and for right visual field stimuli given by the patients with left hemispheric lesions and non-brain-damaged patients. See 'Procedure' in Methods section for explanation of conditions. Under each condition the maximum possible number of correct naming responses was 60 in each visual half-field. (CC = control condition; standard deviations are given in brackets.)

\( \alpha = 0.05 \), no significant differences were found for either group. The performance of the two groups varied in both visual half-fields between 91 and 99% correct responses.

During vibration of the left posterior neck muscles (condition IV) two of the five left brain-damaged patients experienced a consistent visual movement and egocentric displacement of the fixation point (yellow LED) to the right; two patients had no visual illusion and one patient (first uncertain about an impression) later described a movement to the left. In the same patients who experienced a visual illusion, vibration of the right posterior neck muscles (condition V) again induced an impression of movement and displacement of the LED, but now in the opposite direction.

From the group of 15 non-brain-damaged patients, 10 reported a visual illusion of movement and displacement to the right when the left posterior neck muscles were
vibrated. Five patients had no illusion during vibration. In the same 10 patients, vibration of the right posterior neck muscles induced a perception of movement to the opposite side.

In all control patients, vibration of the left hand muscles led to no illusory effects.

**Patients with neglect**

During vibration of the left posterior neck muscles, J.L. experienced a movement and displacement of the LED to the right, whereas, A.D. and M.B. had no sensation of movement. Vibration of the right posterior neck muscles induced no visual illusion in the three patients.

Comparable to controls, left-hand muscle vibration (control condition of J.L. and M.B.) led to no illusory effect in the two patients.

Illustrated in Figs 2–4 are the percentages of correct responses for left visual field

![Graph showing percentages of correct responses for left and right visual fields](image)

**Fig. 2.** Percentage of correct responses for left (▲) and right (■) visual field stimuli given by J.L. under the five test conditions and the control condition. The spatial relationship between the orientation of head and trunk midline is illustrated as seen from above. The trunk is represented by a rectangle, the head by a circle. The arrow indicates the side of neck muscle vibration (s, \( P \leq 0.05 \)).

and for right visual field stimuli given by the three patients under the five test conditions and the control condition. A very similar pattern of responses was found in J.L., M.B. and A.D.

In baseline condition I, the three neglect patients showed the expected significantly different levels of correct responses for stimuli presented in the contralesional left visual field and ipsilesional right visual field (Exact McNemar test, \( \alpha = 0.05 \)). Concerning stimuli presented in the left visual field, the patients gave between 20 and 30% fewer (correct) responses than they were able to give when the stimuli were presented in the right visual field.

In all three patients, the level of right visual field performance did not change throughout
the subsequent test conditions and the control condition. The left visual field deficit, however, improved under conditions II and IV. In comparison with the baseline condition I, turning the trunk to the left (condition II) led to a significant increase of correct responses in all three patients (Exact McNemar test, $\alpha = 0.05$). Improvement could also be
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observed when the left posterior neck muscles were vibrated. The difference between baseline condition I and condition IV was highly significant in J.L. and M.B. (Exact McNemar test, $\alpha = 0.05$). A.D. showed the same positive tendency during vibration, but the observed difference failed significance (Exact McNemar test, $0.05 < P < 0.10$).

In contrast to conditions II and IV, no significant changes of left visual field performance were measured in the other conditions for the three patients. No effect was observed by turning the trunk to the right (condition III), by vibrating the right posterior neck muscles (condition V) or upon sensory stimulation on the left side by vibrating the left hand muscles or turning the head to the left (control condition).

DISCUSSION

Recently, Karnath et al. (1991) observed a compensation of contralateral neglect in patients with right hemisphere lesions by turning the patients' trunk to the contralesional side while head and gaze remained oriented straight ahead. The relative deviation of the trunk midline from the straight ahead head and eye orientation resulted in both left and right visual field stimuli being projected to the right, ipsilesional side of the trunk. The effect was observed for detection of, and saccadic reaction to, contralateral visual targets. The present study allows a generalization of these findings to more complex cognitive operations including the identification of visual stimuli. Under the present conditions, saccadic responses to the stimuli were prevented. Instead (with the exception of A.D.), naming of the stimuli was requested.

Furthermore, it was confirmed by the present results that the head-on-trunk signal induced by the proprioceptive input of the posterior neck muscles has an influence on the extension of the neglected part of space in patients with neglect. The patients' neglect of contralesional left visual field stimuli, observed in baseline condition I when the body was in a normal upright position and midlines of head, trunk and visual field were in parallel, could be reduced by vibrating the left posterior neck muscles as well as by turning the trunk 15° to the left.

In both conditions the same afferent head-on-trunk signal was induced: a relative leftward deviation of the trunk midline from the straight ahead head and eye orientation. By turning the trunk to the left, the afferent proprioceptive input is elicited by the real lengthening of the left posterior neck muscles. The discharge induced by vibration of these muscles leads to the false, but equivalent interpretation that the left posterior neck muscles have lengthened. The compensation of the left-sided neglect during neck muscle vibration seemed to be independent of the presence of a conscious illusion of movement and displacement of the visual stimuli; although the compensatory effect of vibration could be seen in all three patients, only one reported a visual illusion. However, the present data do not permit the assumption of a clear dissociation since the visual illusion may have been absent when it was explicitly tested, but might have been present while the patients performed the tachistoscopic experiments. Biguer et al. (1988), as well as Taylor and McCloskey (1991), mentioned that the visual illusion fluctuated and was sometimes difficult to hold constant.

The results cannot be explained by unspecific arousal and activation due to unspecific sensory stimulation on the contralesional side of sagittal midplane which might have led to an orientation of general attentional processes to that side. Stimulation on the
left of the patient's body by vibrating the left hand muscles as well as the proprioceptive signal induced by turning the head 15° to the left, showed no compensatory effects. Vibration of the right posterior neck muscles and turning the trunk to the right also had no effect on the patients' neglect.

For the latter conditions (III and V) one could expect a worsening of neglect symptoms. In these conditions the real or apparent spatial orientation of trunk midline was turned to the right so that the stimuli lay on the contralesional left side of trunk midline. This expectation was not supported, however, either by the earlier (Karnath et al., 1991) or by the present experiment. A plausible, though not confirmed, explanation could be that the sagittal midplane of the trunk constitutes a border left of which neglect symptoms arise, but will not be amplified with increasing left-sided eccentricity. However, with a trunk rotation (real or apparent) large enough so that the left and right visual field stimuli lie on the contralesional side of the trunk midline, a performance decrement would also be expected for the right visual field stimulus. Such a decrement was not observed, however, in the present or the earlier experiment. The failure to observe neglect of the right visual stimuli under this condition requires further clarification. One could speculate that an automatic initial orientation of attention towards the rightmost stimulus as described by Karnath (1988), De Renzi et al. (1989) and Gianotti et al. (1991), allows for a sufficient analysis of right visual field stimuli (even if these fall to the left of the sagittal midplane of the trunk).

What does the vibration-induced effect, observed in the present study, mean with respect to the mechanisms underlying neglect syndrome? Biguer et al. (1988) speculated that their observations of neck muscle vibration in normal subjects indicate that the input from neck muscle proprioceptors, particularly from the muscle spindles, can participate directly in the elaboration of body-centred visual space. The proprioceptive input influences the computation of the central representation of gaze direction and the signal of velocity with which this direction is changing. The authors found that alteration of proprioceptive input from neck muscles can modify the body-centred representation of visual space in their subjects. During vibration of the left neck muscles, the subjective localization of the subject's sagittal midplane projected into visual space was displaced to the left compared with its physical localization. The displacement influenced the calculation of spatial target coordinates towards which a pointing movement of the unseen hand was directed. Furthermore, it determined the position at which the target was perceived.

It can be hypothesized that the reduction of neglect symptomatology by vibration of the left posterior neck muscles (as observed in the patients with neglect of the present study) is based on the same effect of vibration as that proposed by Biguer et al. (1988) to explain their observation in normal subjects. The authors provided evidence for a shift of the subjective spatial localization of sagittal midplane to the left. This becomes even more plausible when the effect of a real shift of localization, by turning the patient's trunk to the left (Karnath et al., 1991), is taken into account. The subjective and/or objective localization of sagittal midplane in space seem to contribute substantially to the neural generation of the frame of reference which underlies the subject's internal representation of space. In normals, during vibration, the reference for calculation of spatial coordinates used for pointing movements or the determination of the position of an object is systematically displaced to the side of neck muscle vibration (Biguer
et al., 1988). In patients with neglect, by vibration of these neck muscles, the detection and identification by naming of contralaterally located visual objects is improved. The conclusion might be drawn that in neglect patients the disturbed neural representation of space, which underlies impaired perception and localization of spatial targets, limb movements or orienting of overt and covered attentional processes towards these targets, is influenced by the (real or false) proprioceptive information about the instantaneous body orientation with respect to visual space.

According to the results obtained by Karnath et al. (1991), however, the head-on-trunk signal alone cannot account for this effect. Although elongation of left posterior neck muscles was involved in two of the different conditions tested in that study [(i) trunk turned to the left and head oriented straight ahead; (ii) trunk oriented straight ahead and head turned to the right], only the first of these two conditions led to a compensation of contralateral neglect. A very plausible explanation for this difference is an interaction of the eye-in-head signal with the head-on-trunk signal. With respect to the two experimental conditions the elongation of left posterior neck muscles were comparable, but induced different eye-in-head signals. Whereas the eye position in the orbit in the first condition was aligned with the orientation of the patient's head, in the second condition the eye position deviated 15° to the left from head orientation. Experimental evidence for the assumed influence of eye position in the orbit on the proprioceptive signal derived from neck muscles comes from studies in cats. Roucoux et al. (1981) and Vidal et al. (1982) demonstrated that electromyographic activity in many neck muscles is closely related to eye position in the orbit. Further arguments for a functional relationship between neck and eye signals are provided by studies in monkey and man investigating the neck–eye loop (cervico-ocular reflex) and its adaptive changes following loss of vestibular function (e.g. Dichgans et al., 1973; Bronstein and Hood, 1986).

The aforementioned interaction may also be illustrated in the following way. During vibration of the left neck muscles either the trunk (cf. Biguer et al., 1988) is apparently rotated to the left with respect to the head or the head is apparently rotated to the right with respect to the trunk (cf. Taylor and McCloskey, 1991). On the first assumption, the left stimulus is subjectively experienced as to the right of the trunk midline. On the second assumption, when the head (and likewise the direction of gaze) appears to be rotated to the right, the left stimulus will also be experienced as to the right of the (unchanged) trunk midline. With the trunk actually turned to the left (while head and eyes are oriented straight ahead) the left stimulus is perceived as right of the trunk midline. With the head turned to the right (but with the eyes still fixating straight ahead) the extension of the left neck muscles is the same as in the former conditions. However, the left stimulus is now perceived to the left of the trunk midline.

Thus, this would explain why the neglect is reduced during actual rotation of the trunk to the left and apparent leftward rotation of the trunk (or apparent rightward rotation of the head) during vibration of the left posterior neck muscles but not with actual rightward rotation of the head. However, in the present study and that of Karnath et al. (1991), the influence of eye position in the orbit on the signal transmitted from the neck muscles was not systematically investigated and, therefore, its influence can only be assumed on indirect evidence. Closer investigation of the possible interactive effect on the disturbed neural representation of space in patients with neglect is necessary.
In addition to the vibration-induced effect observed in the present study, a transient reduction of neglect symptomatology has been reported for vestibular and optokinetic stimulation in patients with neglect. Silberpfennig (1941) first described a case with temporary remission of visual neglect through peripheral vestibular activation on the ipsilesional side. Rubens (1985) replicated this finding, demonstrating in 17 right brain-damaged patients with left-sided hemineglect that caloric stimulation of the contralesional ear with cold water could reduce the patients' neglect in word reading, line cancellation and pointing to people standing on the left side of their bed. Upon stimulation, all subjects developed a brisk nystagmus to the right and indicated that the task was made difficult by an inability to fixate. Again, it is unlikely that the improvement was due to unspecific arousal produced by stimulation on the patient's left side since vestibular activation with warm water in the ipsilesional ear could elicit the same reduction of neglect symptoms in these patients. Using the same paradigm, Cappa et al. (1987) confirmed these results. The authors observed in their patients an improvement in cancellation, in the ability to point to parts of their upper left extremity and in a regression of anosognosia (the latter in two of their four patients with neglect). Again, during stimulation a brisk nystagmus with the slow phase to the contralesional side was observed. More recently, Bisiach et al. (1991) reported a patient suffering from a right hemispheric lesion, left-sided hemineglect and somatoparaphrenic delusion. The patient's belief that her arm did not belong to her own body was temporarily suppressed by vestibular cold water stimulation in the contralesional ear.

Pizzamiglio et al. (1990) asked non-brain-damaged subjects and right brain-damaged patients, with and without hemineglect, to bisect lines either in the presence of a stationary or a moving background. With the moving background an optokinetic nystagmus was induced with the slow phase in the direction of the movement. Under the moving condition a displacement of the subjective midpoint in the direction of the movement was observed in all three groups of subjects. Concerning the group of neglect patients, optokinetic stimulation with leftward movement of the background reduced the displacements of bisection marks; whereas, optokinetic stimulation to the right markedly increased the displacement.

In all studies which demonstrated a remission of neglect during vestibular or optokinetic stimulation a nystagmus was induced with the slow phase to the contralesional side. Although it is necessary to study the direct influence of the nystagmus-induced change of fixation by eye movements to the contralateral side on the reduction of contralateral visual neglect in more detail, it may be concluded so far that the pure motor act cannot be considered as the sole factor responsible for all of the reported effects in patients with neglect, e.g. decrease of somatoparaphrenic delusion, anosognosia or pointing to contralateral limbs.

Much more plausible is the hypothesis that the afferent information obtained from visual, optokinetic and vestibular input, together with the proprioceptive signals from the neck muscles, is simultaneously used for the elaboration of egocentric coordinates of visual space. Further, it must be assumed that spatial information about many other parts of the body is involved in the specification of body configuration and body orientation within visual space (Lackner, 1988; Roll et al., 1991). According to these authors' observations, position sense and the body schema represent an interaction of multiple afferent and efferent domains. The central nervous system interprets a whole postural
and visual context to generate an egocentric frame of reference. Different neural operations are needed for the generation. For example, when reaching for a stationary object located in the peripersonal space the position of eyes and head vary from moment to moment (due to the usual movements of the subject), although the relevant spatial location of the target with respect to the body may not change. Therefore, it is plausible to assume that the retinotopic coordinates of the target are transformed into a more stable coordinate system based on a body-centred frame of reference. According to Jeannerod (1991), this visuomotor map is centrally combined with a proprioceptive map using the same coordinate system, so that limb position and target position can coincide.

In this context, the observations made in the present study support the hypothesis that the cerebral areas damaged in patients with neglect are critical for the generation of the body-centred reference system of visual space. Damage of this reference system might be the basis for a disturbance of the process by which the afferent information from different peripheral sources is centrally transformed into appropriate spatial (target) coordinates in order to code the correct vectors necessary to orient focal attention as well as certain motor actions within space (e.g. reaching or pointing movements).

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