Neglect in Three Dimensions

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Objectives. Neglect in vertical and radial directions is rarely evaluated systematically in patients with brain damage. Method and Results. Using the line bisection task, we confirmed that some patients with unilateral brain damage manifest vertical or radial spatial neglect. In fact, patients with severe left horizontal neglect tend to have severe vertical neglect. Conclusion. Because vertical and radial neglect may affect the ability to perform functional daily activities, occupational therapists need to address the existence of vertical and radial neglect when evaluating and training patients with brain damage.
age had left hemianopsia, and four subjects with left brain damage had right hemianopsia.

Procedure

To evaluate neglect in three dimensions, we used the line bisection task described in previous reports (Butter et al., 1989; Mennemeier et al., 1992; Rapcsak et al., 1988; Shelton et al., 1990). Lines were located along three orthogonal axes. Subjects were asked to bisect single black lines of 2.5 mm width and of three different lengths (20 cm, 25 cm, and 30 cm), centered on a piece of paper 25.7 cm × 36.3 cm. A set of stimuli of three different lengths was presented in a pseudorandomized fashion in each location. Stimuli were located in eight different areas of extrapersonal space for the subject, along three orthogonal axes (see Figure 1). Horizontal lines were presented in the usual fashion with pages in the transverse plane flat on a tabletop and with lines oriented along the intersecting frontal plane 30 cm in front of the subjects (horizontal condition). Vertical lines were presented on pages 30 cm in front of the subjects at the intersection of the frontal and midsagittal plane (vertical condition). Radial lines were presented on pages in the transverse plane at table level with lines oriented along the intersection of the midsagittal plane (radial condition). Stimuli were placed in three locations along the horizontal axis: with midpoint approximately 30 cm right, (right horizontal condition), 30 cm left (left horizontal condition), or at the midline (central horizontal condition). Stimuli were placed in two locations along the radial axis: with pages adjacent to the body surface (near radial condition) or with the line midpoint approximately 30 cm (far radial condition) from the subjects. Stimuli were also placed in three locations along the vertical axis: with midpoint approximately 30 cm above eye level (upper vertical condition), at eye level (central vertical condition), or 30 cm below eye level (lower vertical condition).

The order of presentation was counterbalanced to control for the effects of practice and fatigue, and test sessions were limited to 30 min. Subjects were required to explore the full extent of the test line before attempting to bisect it. There was no time limit for completion of the task. Subjects were reminded of the instructions when necessary. The test procedure for the control group was the same as that for the experimental group. Deviation from the true midpoint of the lines was measured to an accuracy of 1 mm on a standard ruler. Localization of lesions was examined with computed tomography or magnetic resonance imaging.

Results

Presence of Vertical or Radial Neglect and Neuroradiological Examination

We judged experimental subjects to have horizontal neglect if they located the midpoint outside the mean ± 2 standard deviations from the value located by the controls in any of three horizontal conditions. We judged experimental subjects to have vertical neglect if they located the midpoint outside the mean ± 2 standard deviations from the value located by the controls in any of three vertical conditions. We judged experimental subjects to have radial neglect if they located the midpoint outside the mean ± 2 standard deviations from the value located by the controls in either of two radial conditions.

Two experimental subjects had superior vertical neglect and five had inferior vertical neglect. Three experimental subjects had far radial neglect and three had near radial neglect (see Table 1). These results confirm the existence of vertical and radial neglect in persons with unilateral brain damage. Some subjects with vertical or radial neglect did not have visual field defect. Vertical or radial neglect cannot be explained from visual field defect.

Figure 2 shows diagrams on which the lesions of all subjects with superior vertical neglect were superimposed. Figure 3 shows superimposed lesions of all subjects who had inferior vertical neglect. Figure 4 shows superimposed lesion of all subjects who had far radial neglect. Figure 5 shows superimposed lesions of all subjects who had near radial neglect. Lesions extended over wide regions in the right frontal, temporal, and parietal lobe and basal ganglia.

Relation Between Horizontal Neglect and Vertical or Radial Neglect

All subjects with vertical or radial neglect also had left horizontal neglect; therefore, we examined the relation
between horizontal neglect and vertical or radial neglect. Subjects with brain damage were divided into four groups according to the existence of left or right horizontal neglect.

Group A consisted of 13 subjects with right brain damage with left horizontal neglect; they had an average age of 68 years and a mean time since onset of 7.8 months. Group B consisted of 13 subjects with right brain damage without left horizontal neglect; their average age was 60 years and mean time since onset was 10.6 months. Group C consisted of 4 subjects with left brain damage with right horizontal neglect; they had an average age of 66 years and a mean time since onset of 9.5 months.

Group D consisted of 9 subjects with left brain damage without right horizontal neglect; their average age was 65 years and mean time since onset was 9.3 months.

We compared means of absolute values of deviation between controls and each of the four groups with analysis of variance (one-way classification method). Significant differences ($p < 0.01$) were revealed on the respective planes between the control group and the group with right brain damage with left horizontal neglect, while significant differences were not shown between the control group and the other three groups (see Table 2). This finding indicates that left horizontal neglect may be related to vertical or radial neglect.

### Table 1

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Left Horizontal Neglect</th>
<th>Vertical Neglect</th>
<th>Radial Neglect</th>
<th>Visual Field Defect</th>
<th>Etiology</th>
<th>Lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>77</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>CI</td>
<td>Rt-F, T, P, BG</td>
</tr>
<tr>
<td>2</td>
<td>73</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>CI</td>
<td>Rt-F</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>CI</td>
<td>Rt-F, BG</td>
</tr>
<tr>
<td>4</td>
<td>73</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>CI</td>
<td>Rt-F, P, T</td>
</tr>
<tr>
<td>5</td>
<td>76</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>CI</td>
<td>Rt-P</td>
</tr>
<tr>
<td>6</td>
<td>79</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>CI</td>
<td>Rt-F, T, P, BG</td>
</tr>
<tr>
<td>7</td>
<td>80</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>CH</td>
<td>Rt-T, P, O</td>
</tr>
<tr>
<td>8</td>
<td>67</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>CI</td>
<td>Rt-BG</td>
</tr>
<tr>
<td>9</td>
<td>74</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>CI</td>
<td>Rt-F, T, P</td>
</tr>
</tbody>
</table>

*Note:* + = exists, - = does not exist.

Cl = cerebral infarction, CH = cerebral hemorrhage, Rt = right, F = frontal lobe, P = parietal lobe, T = temporal lobe, O = occipital lobe, BG = basal ganglia.

**Figure 2.** Overlapped lesions of subjects showing superior vertical neglect ($n = 2$).

**Figure 3.** Overlapped lesions of subjects showing inferior vertical neglect ($n = 5$).
Next, we evaluated whether there was a correlation between the severity of left horizontal neglect and the severity of vertical or radial neglect. Data for right horizontal, central horizontal, and left horizontal conditions were summed and used as data for horizontal condition. Data for upper vertical, central vertical and lower vertical conditions were summed and used as data for vertical condition. Data for far radial and near radial conditions were summed and used as data for radial condition. We calculated a correlation coefficient and verified it with a $t$-test. A correlation coefficient between horizontal deviation and vertical deviation was 0.83, which was significant ($p < 0.01$). A correlation coefficient between hori-

![Figure 4. Overlapped lesions of subjects showing far radial neglect ($n = 3$).](image)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control (mm)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper vertical</td>
<td>4.1</td>
<td>10.6*</td>
<td>5.0</td>
<td>2.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Central vertical</td>
<td>4.3</td>
<td>9.7*</td>
<td>5.1</td>
<td>4.7</td>
<td>4.5</td>
</tr>
<tr>
<td>Lower vertical</td>
<td>4.2</td>
<td>11.5*</td>
<td>5.2</td>
<td>6.7</td>
<td>3.1</td>
</tr>
<tr>
<td>Far radial</td>
<td>3.7</td>
<td>8.8*</td>
<td>4.8</td>
<td>2.2</td>
<td>4.7</td>
</tr>
<tr>
<td>Near radial</td>
<td>4.4</td>
<td>9.4*</td>
<td>4.4</td>
<td>5.9</td>
<td>4.2</td>
</tr>
</tbody>
</table>

*Note.*
A = Right brain damage with left horizontal neglect.
B = Right brain damage without left horizontal neglect.
C = Right brain damage with right horizontal neglect.
D = Right brain damage without right horizontal neglect.

$p<0.01$

horizontal deviation and radial deviation was 0.42, which was not significant. The results indicated that subjects with severe left horizontal neglect tended to have severe vertical neglect, and we cannot presume the severity of radial neglect from the severity of horizontal neglect.

**Discussion**

A few studies have reported neglect in the vertical or radial directions (Butler et al., 1989; Mennemeier et al., 1992; Rapcsak et al., 1988; Shelton et al., 1990); all of these used subjects with bilateral brain lesions. Our study found that some subjects with unilateral brain damage manifest neglect in the vertical or radial direction. This finding indicates that we should attend to the existence of vertical or radial neglect, even in persons without bilateral lesions.

Our study also showed that overt neglect in the vertical or radial direction existed only in the subjects who had right brain damage and showed left horizontal neglect. This finding implies that the severity of horizontal neglect was correlated with the severity of vertical neglect. However, the severity of horizontal neglect was not correlated with the severity of radial neglect. This finding implies that there is a common mechanism underlying horizontal neglect and vertical neglect, but that radial neglect may have a different mechanism.

Mennemeier et al. (1992) suggested that inferior ver-
tical neglect and near radial neglect may be associated with bilateral parietal lobe lesions, and superior vertical and far radial neglect may be associated with bilateral inferior temporooccipital lesions. However, our study did not support such an association (see Table 1). We could not find such a dichotomy of localization in subjects with brain damage (see Figures 2 to 5). This discrepancy might exist because Mennemeier and colleagues drew their hypothesis from few subjects with bilateral lesions. Even our neuroradiological examination did not permit us to specify the localization of vertical or radial neglect. Further systematic study is needed to address this discrepancy.

Conclusion

In daily life, vertical or radial neglect could cause impaired functions, although those have not received serious attention in the literature. Some possible examples of impaired functions due to vertical or radial neglect are mishandling of a wheelchair (e.g., not placing feet on foot rest or trying to stand up with the feet on the foot rest), tripping over an unnoticed obstacle, hitting the head on an unnoticed object, attaching or applying a leg brace inadequately during a walk, or forgetting to remove shoes or socks. These impaired functions are usually considered to derive from severe sensory disorder, paralysis, autotopagnosia, anosognosia, or unilateral horizontal neglect. If, by using the line bisection task, we properly evaluate the sources of those impairments as arising from vertical and radial neglect, we could prevent potential hazards to patients with brain damage by helping them pay attention to neglected vertical or radial spaces.

References