Reaching in Stroke with Hemiplegia: The Error between Estimated and Actual Distances in the Visual Field

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Abstract. The aim of this study was to examine patients with post-stroke hemiplegia for space estimation disorder during visual reaching for a target. Six patients with post-stroke hemiplegia with no parietal damage were studied, as well as 6 healthy older adults and 6 healthy younger adults as a control group. A target was placed on the table in front of the subject, and then the subject was asked to verbally indicate the farthest reachable point while the target was gradually being moved further away from the subject. The difference was then obtained by measuring the distance from the subject to the indicated point. There was no significant difference in the errors between the estimated and actual values in the healthy older and younger adults. No significant difference was also observed between dominant and non-dominant hands. There were significant differences between the paretic and non-paretic side in the hemiplegic patients, as well as between the paretic side of hemiplegic patients and the dominant hand in the healthy older adults. Compared with healthy subjects, the hemiplegic patients showed a greater difference between the estimated and actual values for both the non-paretic and paretic sides, which indicates an estimation disorder during visual reaching in patients with post-stroke hemiplegia. These results are discussed based on a conversion of the visual coordinates into movement coordinates during visual reaching.

Key words: Reaching, Estimation, Hemiplegia

INTRODUCTION

In general, people can instantaneously perceive the position, size, and inclination of a target so that they can reach and grasp it1). The positional information of the target in a visual coordinate system is obviously crucial for reaching. The perception that determines reachability is attained from the integration of visual coordinates within an egocentric reference frame and articular coordinates in a self-body image2–8). Arbib1) indicated that the reaching control of the upper extremities acts as a way of guiding the hand, distal from the wrist, so that the hand can be moved to the target. The control system for this process is assumed to be the visual system, which determines the position of the object, i.e. the control system of the upper extremities operates based on the perception of an object in space. In this manner, people can determine the reachability of an object based on spatial perception, as well as self-body image.

To determine motor control, such as “how to move”, spatial perception of the object is essential. This comes directly from neurophysiological evidence that a readiness potential can be seen in the parietal association area before dealing with an object9,10). A motor program is then constructed based on the self-body image accumulated in the
parietal association area\(^{11}\).

In general, patients with spatial perception disorder or deterioration of the body image due to parietal damage are classified as hemispatial neglect and asomatognosia, respectively. It is presumed that the spatial perception of an object and the self-body schema cannot be integrated due to perceptual alteration after paralysis in stroke patients without parietal damage.

In this study, the error between the estimated and actual distances during visual reaching in patients with post-stroke hemiplegia was determined, and the integration process disorder between external visual information and the internal body image was investigated.

**METHOD**

**Subjects**

Six patients with post-stroke hemiplegia participated, and all patients gave their written informed consent. Of these, four patients had a brain infarction and two patients had an intracerebral hemorrhage. All of the patients were confirmed to have no damage in the parietal lobe or in its marginal area by CT and MRI. Three patients had left hemiplegia and three patients had right hemiplegia. None of them had any independent voluntary movement in the upper extremities, but synergic movements were observed. The mean age was 68.8 ± 7.5 years. All of the patients were confirmed to have no impairment of their visual functions or higher brain functions based on a cranial nerve test and other various tests for higher brain functions. None of the patients had a history of orthopedic diseases in the upper extremities.

Twelve healthy adults who gave their written informed consent were studied as controls; six of them were in their third decade of life (healthy youth group) and the remaining six were in their eighth decade of life (healthy older group) with mean ages of 22.6 ± 1.0 and 72.1 ± 3.6 years, respectively.

**Procedure**

In this experiment, the estimated and actual reachable distances were obtained using only motion of the upper extremities with the trunk immobilized. First, on a desk placed in front of the subject, two lines parallel to the frontal plane (referred to as two reference lines) were drawn on both the right and left side —0 and 180 degrees— of the subject. Five lines were then drawn radially at 30-degree intervals between the two reference lines. The desktop used in this study was 75 cm long and 300 cm wide, and circular cylinders 2.5 cm in diameter with a height of 10.0 cm were used as objects. The objects were placed on each line 15.0 cm from the midpoint in front of the subject and were moved at 2.5 cm intervals on the line away from the subject. The subjects were asked to verbally describe the reachable positions, the distance from the midpoint to which was measured and recorded (Fig. 1).

When the estimated distance was obtained for the right arm, the two reference lines on the right and left sides were given as a starting angle (0°) and an ending angle (180°), respectively. For the left arm, the left and right reference lines were supposed to be a starting angle (0°) and an ending angle (180°), respectively. The angular lines used or estimate measurements were chosen randomly. The subjects were allowed to move their head and neck freely. The actual reachable value was obtained by stretching the subjects’ upper extremities passively, with the help of an examiner with the subject’s trunk immobilized. Measurements were obtained for the paretic and non-paretic sides of the
hemiplegic patients and the dominant and non-dominant hands of the control subjects.

The subjects were in a sitting position in a wheelchair or chair with their lower trunk in contact with the desk. All subjects were asked to put their hands on their knees during the estimates.

Data analysis
The differences between the estimated and actual reachable distances were obtained. The absolute error (hereinafter referred to as error) was obtained by removing the positive or negative sign.

For the healthy subjects, a three-way analysis of the variance was used for testing the error between the elder and younger subjects, the dominant and non-dominant hands, and the angles. For the hemiplegic patients, a two-way analysis of the variance was used for testing the error between the paretic and non-paretic sides and the angles. A two-way analysis of the variance was also used for the data of the dominant hand of the healthy elders, the non-paretic and paretic sides of the hemiplegic patients, and each angle’s factor. The Scheffe method was used as a post-hoc test. All data were processed using SPSS 12.0J for Windows, and differences with a p value of <0.05 were considered to be statistically significant.

RESULTS

Table 1 shows the mean errors and standard deviations of the paretic and non-paretic sides of patients with post-stroke hemiplegia and the dominant and non-dominant hands of the control subjects.

<table>
<thead>
<tr>
<th>Hemiplegia</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paretic</td>
<td>Non-paretic</td>
</tr>
<tr>
<td>0°</td>
<td>9.6 ± 5.8</td>
</tr>
<tr>
<td>30°</td>
<td>11.9 ± 9.3</td>
</tr>
<tr>
<td>60°</td>
<td>13.8 ± 9.6</td>
</tr>
<tr>
<td>90°</td>
<td>16.8 ± 9.4</td>
</tr>
<tr>
<td>120°</td>
<td>14.6 ± 10.6</td>
</tr>
<tr>
<td>150°</td>
<td>14.3 ± 7.9</td>
</tr>
<tr>
<td>180°</td>
<td>11.5 ± 6.1</td>
</tr>
</tbody>
</table>

Testing error in the control group
The three-way analysis of the variance revealed that there was no significant difference between the healthy elder and younger subjects (F=1.38, p=0.24), the dominant and non-dominant hands (F=0.81, p=0.37), or the angles (F=1.44, p=0.20), and no interaction among the subjects was observed.

Testing error in patients with post-stroke hemiplegia
The two-way analysis of the variance revealed that there was no significant difference between the non-paretic and paretic sides (F=1.04, p=0.31) or the angles (F=1.59, p=0.09).

Testing error for the dominant hand of the healthy elders and patients with post-stroke hemiplegia
The two-way analysis of the variance revealed that there was a significant difference in the dominant hand of the healthy elders and the non-paretic and paretic sides of the hemiplegic patients (F=20.23, p<0.001). Multiple comparisons revealed that there was a significant difference in the errors between the dominant hand of the healthy elders and the paretic side of the hemiplegic patients, as well as between the dominant hand of the healthy elders and the non-paretic side of the hemiplegic patients (p<0.001). There was no significant difference between the paretic and non-paretic sides (p=0.24), and also no significant difference was observed for the angles (F=1.38, p=0.15).

DISCUSSION

The results of this study showed that there was no
significant difference in the error involving distance estimates during visual reaching and the actual distance to an object between healthy elders and younger people, indicating that the ability to estimate distances, as tested in this study, does not decline with age. In addition, no difference was observed between the dominant and non-dominant hands or between the angles. On the other hand, the distance estimates involving the dominant hand of the healthy elders differed significantly from the paretic and non-paretic sides of the hemiplegic patients, which indicates that hemiplegic patients have an estimation disorder that affects visual reaching on the paretic as well as the non-paretic side. This is evident based on the fact that there was no significant difference in the error between the non-paretic and paretic sides.

During reaching, basic information to help in perceiving the position of the object as well as visual information is gathered. The perceived positional information and visual and somatosensory information are then integrated to reach the object. Additionally, where the object is positioned within the visual space is recognized and how to move the many joints of the arm is calculated in order to reach the object. A coordinate system in the objective visual space is called a visual coordinate system, and the system for generating the movement necessary for reaching the object is called a movement coordinate system. Visual information is received by the retina and processed in the retina-centered coordinates, and this information is transformed into body-centered coordinates in the association cortex; i.e. the process of collation of external information with the conditions of the self-body image. The coordinate transformation during visual reaching consists of determination of the objective point to be reached using the body-centered coordinates followed by calculation of the arm movements. The position of the objective point relative to the arm is then calculated, followed by the transformation into a joint angle and into the lengths and tensions of the muscles needed to achieve the required angle.

It is well known that dissociation of “near space” and “far space” occurs after brain damage. In this experiment, it was demonstrated that there is impairment in the body image in the self-centered reference frame based on the “near space” and self-body. The “near (reachable) space” is assumed to be encoded in the somatomotor space, and its locus is believed to be in 7b area and in the pathway linking the intraparietal sulcus with the ventral premotor cortex.

The results of this study show that there was a larger error between the estimated and actual distances involved in reaching for an object in patients with post-stroke hemiplegia. There may be two factors accounting for this. First, if there is impairment during the perception process regarding the position of the object in the visual coordinate system, it is possible that the coordinate transformation may be impaired. This is supported by the fact that there was no significant difference in the error between the paretic and non-paretic sides. If a higher nervous function was responsible for the transformation process from visual information into the articular coordinate system, the error between the estimated and actual distances in both the paretic and non-paretic sides might increase. The second possible factor might involve the process in which the perceived positional information is integrated with the visual and somatosensory information. During the actual movement, the visual information is transformed by a motor program that outputs motor commands while these motor commands are efference copy in the parietal association area to form a body image. However, if the patients with post-stroke hemiplegia have impairment in the integration between these sensory processes, a mental image of the paretic arm movement may be difficult to generate, because somatosensory information is difficult to transfer to, for example, the muscle receptors on the paretic side. However, this does not explain the increased error between the estimated and actual distances on the non-paretic side. In this study, the actual values were obtained by moving the arm passively, while estimates were determined under the movement image that is not certain to be one in the articular coordinate system (shoulder). Therefore, it is assumed for the time being that the first factor had a greater impact on the error. No significant difference in the error between the angles indicates that the estimation impairment does not occur only in the space associated with the paretic side.

External visual information is inseparable from internal body image. Feed-forward control such as the programming and controlling of reaching operates under the movement image which is derived from the self-body image. Therefore,
repairing this estimation error might be inherent in the arm motor learning process in patients with post-stroke hemiplegia. However, to establish the motor learning process was not investigated in this experiment. A longitudinal analysis will be needed for the evidence that a movement image is necessary for the voluntary expression of arm movement.

REFERENCES