Dissociation of body-centered and stimulus-centered representations in unilateral neglect

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Article abstract—*Background:* Previous studies on unilateral neglect have shown that there are at least two types of neglect—i.e., body-centered and stimulus-centered neglect. These symptoms suggest that the human brain has at least two different reference frames for processing external space. It is unknown, however, whether these two frames are represented independently in the brain and if so, which areas (or networks) of the brain are responsible for each frame of reference. *Objective:* To determine whether body-centered neglect and stimulus-centered neglect can be dissociated in patients with brain injury. *Methods:* New figure discriminative cancellation tasks were designed to simultaneously assess body-centered neglect and stimulus-centered neglect. Two neglect patients with lesions located in different anatomic regions were required to circle every complete figure and to cross out every figure with a missing portion on a sheet of white (29.7 \times 42 cm) paper. *Results:* Patient 1 omitted leftward stimuli on the paper, but the stimuli he found were correctly circled or crossed out. On the other hand, Patient 2 marked stimuli across the paper although he mistakenly circled stimuli that were missing a portion of their left side. Neither patient manifested interaction between the two types of neglect. *Conclusion:* The results of this study clearly showed double dissociation between the two types of neglect. Furthermore, it not only provides evidence that there are two distinct systems of reference frame for external space in the human brain, but also adds new knowledge indicating that these two systems function independently, at least in part. NEUROLOGY 2001:57:2064–2069

Unilateral neglect (UN) is defined as the failure to attend to the side of contralesional space.¹ This symptom is often observed as left UN following damage to the right hemisphere. Previous studies have reported different types of UN, suggesting that there are different kinds of spatial representations that likely reflect different aspects of spatial information processing. It remains unknown, however, whether these different frames are represented independently in the brain and if so, which areas (or networks) of the brain are responsible for each frame of reference.

Previous studies on UN have shown the possible presence of two frames of reference for external space—i.e., viewer-centered and stimulus-related frames. The viewer-centered frame is defined in relation to the midline of the body (or trunk) or body parts and may be subdivided into retino-, head-, and body-centered frames.²⁻¹⁰ Many researchers have argued that the body-centered frame is disrupted in neglect patients.^{2,5-7,9}

Stimulus-related neglect is an omission or inattention to one side of a stimulus irrespective of its location in relation to the body and had been described as stimulus-centered¹¹⁻¹⁴ or object-centered neglect.¹⁵⁻²⁰ Stimulus-centered neglect is defined as an omission or inattention to the contralesional side of an individual stimulus irrespective of whether the stimulus has a canonical axis or not. In this type of neglect, the direction of the gravity is applied as a referential axis. Object-centered neglect is defined as an omission or inattention to the contralesional side of an individual object in canonical orientation and, by definition, it is observed only when the stimulus has a canonical axis. Axis-based neglect²¹ is a kind of object-centered neglect because the neglected side of an object is determined by the reference axis.

Some investigators have reported that bodycentered and stimulus-centered frames were simultaneously disrupted, suggesting that these two frames of reference are not independent, but are based on a certain common mechanism or an interacting mechanisms.^{22,23} From a review of UN studies, it was concluded that body-centered and stimuluscentered neglect may not be clearly separated.²⁴ So far, no report has shown that body-centered and stimulus-centered frames of reference function independently when stimuli to be attended to and stimuli used as a frame are identical.

We investigated the effect of the body-centered and stimulus-centered frames of reference on two UN patients to elucidate whether the two frames can

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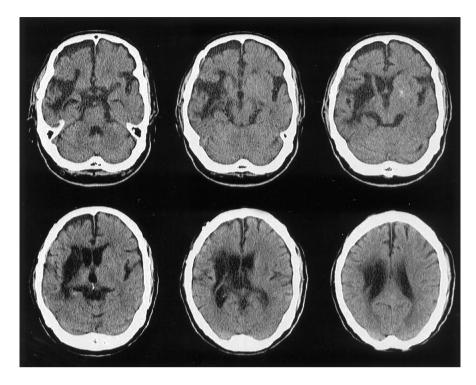


Figure 1. CT scan of Patient 1 performed 9 months after the onset. The lesion was located mainly in the right putamen and the superior and posterior subcortical portions of the surrounding areas, the right insula, the anterior superior temporal gyrus, and the posterior inferior frontal gyrus. The left side of the figure is the right side of the brain.

be differentially damaged. For this purpose, newly developed figure discriminative cancellation tasks were employed.

Patients and methods. *Patients.* Two patients with UN participated: Patient 1 9 months after the stroke and Patient 2 5 months after the stroke. Patients gave their informed consent prior to study.

Patient 1 was a 55-year-old, right-handed male truck driver. He had right hemisphere intracerebral hemorrhage. On neurologic examination, he showed left homonymous hemianopia by confrontation, but had no limitation of eye movement. He had a severe left hemiparesis including the face, a mild left sensory disturbance, and severe left UN. On a 240-mm line bisection task, his subjective midpoint was deviated 14.3% to the right. On a circle crossing out task,²⁵ he omitted stimuli on the left side of the stimulus paper. A brain CT scan 9 months after the stoke showed an extensive lesion involving mainly the right putamen, the superior and posterior subcortical portions of the surrounding area, the right insula, the anterior superior temporal gyrus, and the posterior inferior frontal gyrus (figure 1).

Patient 2 was a 70-year-old, right-handed man who had retired from fishery. He had right hemisphere cerebral infarction. He had a history of subarachnoid hemorrhage due to the rupture of an aneurysm of the right middle cerebral artery and had undergone a clipping operation 23 years previously. This episode did not result in any aftereffects. On neurologic examination, he showed a left homonymous hemianopia by confrontation. There was no limitation of eye movement. Severe left hemiparesis, including the face, and a left-sided sensory disturbance were present. On a 240-mm line bisection task, his subjective midpoint was deviated 11.7% to the right, but there was no omission on the circle crossing out task.²⁵ A brain CT scan 6 weeks after the stroke showed a large infarction in the territory of the right middle cerebral artery, mainly involving the inferior parietal lobule and the posterior part of the superior and middle temporal gyri. A small infarction in the left putamen was also detected (figure 2).

Methods. *Stimuli.* To search for body-centered or stimulus-centered neglect, new figure discriminative cancellation tasks were designed for this study.

Circle discriminative cancellation task. Twenty circles and forty pseudo-circles, each with a diameter of 15 mm, were drawn in a random manner on a sheet of white paper $(29.7 \times 42 \text{ cm})$ and were arranged evenly on either side of the vertical midline of the paper. Half of the pseudo-circles had a missing portion on the right side, and the rest had a missing portion on the left side. The size of the missing portion of a pseudo-circle was one sixth of the circumference of the circle. Thus, it looked like a C or a reversed C.

Triangle discriminative cancellation task. Twenty equilateral triangles and forty pseudo-triangles, each with 15-mm sides, were drawn in a random manner on a sheet of white paper $(29.7 \times 42 \text{ cm})$. They were arranged evenly to each side of the vertical midline of the paper. Half of the 40 pseudo-triangles had a missing portion on the right side, and the rest had a missing portion on the left side. Half of the three kinds of triangles were inverted. Each triangle, with one-third of its apex missing at either side, was like a tilted isosceles trapezoid, because the cut end was closed, unlike the pseudo-circle, which was left open.

Procedure. A session consisted of four trials—i.e., two circle and two triangle discriminative cancellation tasks. The same tasks were performed successively so as not to complicate a session; e.g., the first two trials were circle discrimination tasks, the last two were triangle discrimination tasks. In the second application of each task, the stimulus paper was presented upside down. Another session comprised of the same four trials was performed on another day. Thus, each patient performed eight trials (four circle and four triangle discriminative cancellation tasks).

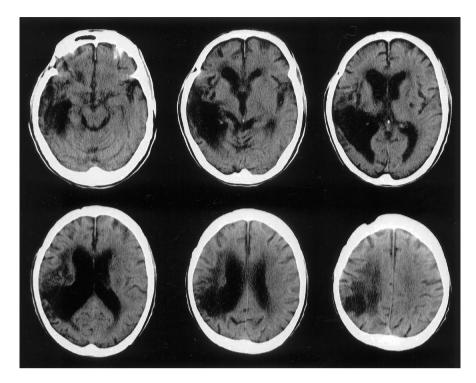


Figure 2. CT scan of Patient 2 performed a month after the onset, showing a lesion in the territory of the right middle cerebral artery. The lesion mainly involved the inferior parietal lobule and the posterior superior and middle temporal lobes. A small infarction in the left putamen was also present.

The patient was seated at a desk. Each stimulus sheet was placed on the desk at the midsagittal plane of the patient's body. The patients were instructed to circle every complete circle (or triangle) and to cross out every incomplete circle (or triangle) with a pen held in the right hand. No restrictions were imposed on movement of the head or eyes. When they finished a task, they were asked whether they had checked all of the stimuli, and whether they were sure they had not made any mistakes. There was no time limit.

Analysis. Omissions on a left side of the paper were regarded as body-centered neglect. Circling of a stimulus with a missing left portion was regarded as stimulus-centered neglect.

To investigate body-centered and stimulus-centered neglect, two analyses were carried out for each patient. The first analysis was performed to examine whether bodycentered neglect was present using the total number of responses. The total number of stimuli that were either circled or crossed out was calculated, regardless of whether subjects made correct judgments about which stimuli to circle or cross out. Second, to investigate whether stimulus-centered neglect was present, the number of stimuli that were correctly circled and crossed out (consistent with appropriate attention to and processing of both sides of the pertinent stimulus) was calculated. Each patient's data were analyzed using two-way analysis of variance (ANOVA) with the body-centered frame (right, left) and stimulus-centered frame (left side missing, no missing part, and right side missing).

Results. Figures 3 and 4 show typical performances of each patient. *The number of responses (body-centered effect)*. Patient 1. The results of ANOVA revealed a main effect for the body-centered frame (F = 32.06, df = 1,42; p < 0.001). There were fewer responses for the left side of the body-centered frame (M = 17.00, SD = 9.96) than for the right side (M = 29.00, SD = 1.07). There was no main

effect for the stimulus-centered frame (F = 0.38, df = 2,42, ns; left side missing: M = 15.38, SD = 3.38; no missing part: M = 14.63, SD = 2.92; right side missing: M = 16.00, SD = 3.63), and no interaction between these two factors (F = 0.45, df = 2,42, ns).

Patient 2. The results of ANOVA showed no main effects for either the body-centered frame (F = 0.78, df = 1,42, ns; left side of the body: M = 28.38, SD = 1.69; right side of the body: M = 27.50, SD = 4.21), or the stimulus-centered frame (F = 0.48, df = 2,42, ns; left side missing: M = 18.75, SD = 2.19; no missing part: M = 18.50, SD = 1.69; right side missing: M = 18.63, SD = 2.07). There was no interaction between these two factors (F = 0.16, df = 2,42, ns).

Figure 5 shows the mean number of total responses for each stimulus in the left and right space.

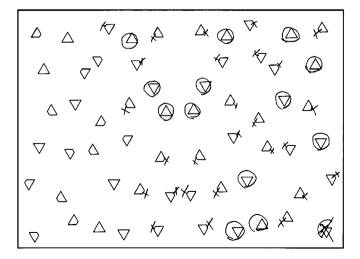


Figure 3. Example of Patient 1's typical performance. The left side of the sheet was located on the left side of the body axis.

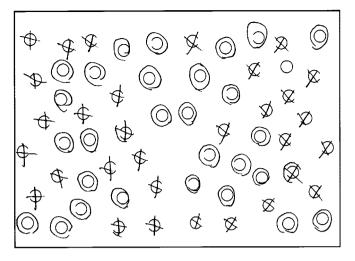


Figure 4. Example of Patient 2's typical performance.

The number of correct responses (stimulus-centered effect). Patient 1. The results of ANOVA revealed a main effect of the body-centered frame (F = 31.35, df = 1,42; p < 0.001). There were fewer correct responses for the left side of the body-centered frame (M = 17.00, SD = 9.96) than for the right side (M = 28.75, SD = 0.89), indicating that he responded to fewer stimuli on the left side of the paper than on the right. There was no main effect for the stimulus-centered frame (F = 0.38, df = 2,42, ns; left side missing: M = 15.25, SD = 3.58; no missing part: M = 14.50, SD = 2.83; right side missing: M = 16.00, SD = 3.63) and no interaction between these two factors (F = 0.38, df = 2,42; ns).

Patient 2. The results of ANOVA revealed a main effect for the stimulus-centered frame (F = 27.27, df = 2,42; p < 0.001). There was no main effect for the body-centered frame (F = 0.77, df = 2,42, ns; left side of the body: M = 23.00, SD = 3.89; right side of the body: M = 21.50, SD =

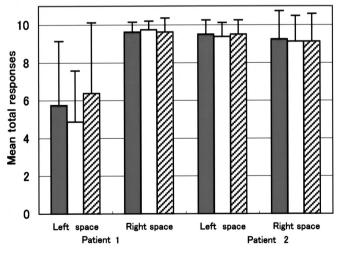


Figure 5. Mean number of total responses for each stimulus in the left and right space. Solid columns represent mean number of responses for stimuli that had a missing portion of their left side, open columns for stimuli that had no missing portion, and hatched columns for stimuli that had a missing portion for their right side. The lines above each column represent the SD of the mean.

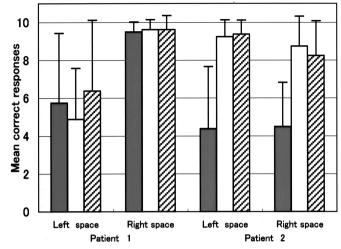


Figure 6. Mean number of correct responses for each stimulus in the left and right space. Solid columns represent mean number of correct responses for stimuli that had a missing portion of their left side, open columns for stimuli that had no missing portion, and hatched columns for stimuli that had a missing portion for their right side. The lines above each column represent the SD of the mean.

4.69) and no interaction between these two frames (F = 0.40, df = 2,42; ns). Post-hoc analysis using Fisher's protected least significant difference method revealed that correct responses were fewer for the left side missing stimuli (M = 8.86, SD = 5.38) than for the no missing part stimuli (M = 18.00, SD = 1.69; p < 0.001) and the right side missing stimuli (M = 17. 63, SD = 2.32; p < 0.001). No difference was found between the number of correct responses for stimuli with no missing part and for those with the right side missing.

Figure 6 shows the mean number of correct responses for each stimulus in the left and right space.

Discussion. In this study we developed a task that distinguishes body-centered and stimulus-centered neglect within one task. Neglect that could be identified as failure to attend to the stimuli on a sheet of paper in relation to the midline of the body was regarded as body-centered neglect, whereas neglect that could be identified at the level of a component stimulus was regarded as stimulus-centered neglect. The multiple line bisection task,²⁶ in which subjects are asked to bisect each of the horizontal lines distributed across a white paper, may fulfill the same objectives as our new task, if the lines do not go across the midline of a stimulus paper. The original line cancellation task,²⁷ in which subjects are requested to check every line across a white paper, may also fulfill the same objectives if the lines are arranged horizontally and we ask subjects not to simply check but to bisect each of the lines.

Patient 1 omitted more stimuli on the left side of the stimulus paper irrespective of the types of stimulus. Yet for the stimuli he marked, responses were fairly accurate. There was no interaction between body-centered neglect and stimulus-centered neglect with regard to either the total number of responses or correct responses. Thus he showed body-centered neglect without stimulus-centered neglect. In contrast, Patient 2 responded to stimuli on both sides of the paper, but he made more mistakes with the stimuli having a missing portion on the left than with the other two types of stimuli. No interaction was detected between the two types of neglect with regard to either the total number of responses or correct responses. He thus showed stimulus-centered neglect without body-centered neglect. This double dissociation is most interesting as it suggests that the underlying mechanisms that support the two types of attention i.e., body-centered attention and stimulus-centered attention—can operate independently.

Body-centered attention or a body-centered frame of reference for spatial vision has been extensively studied. Ocular exploration of left neglect patients was found to deviate to the right in darkness.⁷ The reaction time to stimuli located in the left visual field was prolonged in left neglect patients, but shortened when they rotated their trunks to the left.⁵ Tactile exploration is also improved when stimulus is presented to the right relative to the body.⁹ These data suggest the importance of the body-centered frame for spatial attention. Other studies have reported that left neglect patients showed deviation of the pointing hand to the right relative to the body when they were asked to point straight ahead.^{2,6} This general deviation of body-centered attention toward the right can be explained as a disruption of the frame of body-centered reference on the left. Neglect shown by Patient 1 belongs to this type.

Stimulus-centered attention or a stimuluscentered frame of reference for spatial vision has also been well studied. Some patients with left neglect failed to copy the left side of each figure in a scene.²⁸ Patients with stimulus-centered neglect misread the left portion of words^{12,13} and omitted the left side of pictures.¹¹ Another patient omitted the left side of a chimeric face even when it was presented in the right space of the body.¹⁴ Furthermore, a neglect patient was able to recognize the right contour of a geometric figure on the left side of a page, but failed to recognize its left contour located on the right side of the page.²⁹ These cases were interpreted as showing disruption of attention toward an object, but not toward the wider space. Similarly, subjective midpoints on the line bisection task deviated to the right even when lines were placed in the right hemispace relative to the midline of the body, indicating the effect of stimulus-centered neglect.8 Patient 2's neglect belongs to this type of neglect.

Some studies have attempted to manipulate two types of attentional frames in the same subject. For instance, neglect patients were asked to take photographs so that an object appeared to be in the center. Some put the object on the right side, showing bodycentered neglect, whereas others put the object on the left side, showing stimulus-centered neglect.³⁰ Even though neglect patients may show only one

type of neglect, it is impossible to evaluate how much another type of neglect contributes to their performance. Another study reported that one patient with neglect misread first letters of words irrespective of their spatial positions, whereas another patient with neglect misread the first letters of words and his performance became worse when the words were presented to the left.³¹ From these results, it is possible to say that the stimulus-centered frame may be disrupted alone, but it is not clear whether the bodycentered frame may be disrupted alone, because the latter seemed to show both stimulus-centered and body-centered neglect. In another study,²² line drawings of various objects within which letters were randomly scattered were used to dissociate stimuluscentered and body-centered representation. Left neglect patients were asked to identify a drawing on a sheet of paper and read all the letters in it. Subjects' axes were changed 90 degrees by having them lie down on either side, while the paper's axis was changed 90 degrees by rotating it clockwise or counterclockwise to manipulate the axis of representational reference. Based on their results, the authors concluded that both types of reference were affected to the same degree in their left neglect patients. However, recent reanalysis³² of their data showed that the two references were in fact differentially affected. Thus, one patient showed body-centered neglect only, and the others showed stimulus-centered neglect only. This finding is consistent with the current results. However, there is a difference between two studies that should be emphasized. In their study, the stimulus used to detect stimulus-centered neglect (letter) and that used as a stimulus-centered frame (drawing) were different. In our study the stimuli served for both references. In this regard, the testing method employed in this study is more suitable for dissociating the two types of neglect.

We interpreted the results of this study within the context of body-centered and stimulus-centered frames of reference. Alternatively, our results may be interpreted as a dissociation between a disorder of intention and attention,¹ or between exploratory-motor and sensory-perceptual components of attention.³³

It is clear that the type of attention needed to span the whole paper must employ motor or intentional activity such as ocular scanning or head motion more often than the type of attention needed to identify a small target like a triangle or a circle. Unfortunately, we have not collected the kind of data that would allow us to address the relationship between the traditional attentional theories of neglect and the reference frame theory of neglect.

Patient 1 had lesions in the right putamen, its surrounding region including the insula, the anterior portion of the superior temporal gyrus, and the posterior portion of the inferior frontal gyrus. Patient 2 had cortico-subcortical lesions in the right parietotemporo-occipital area. Both types of neglect have been reported in patients with lesions in the right parietal area, although the extent of lesion is not consistent even with the same type of neglect.^{6,9,14,25,29}

With the extensive lesions of the two patients in this study, it is difficult to make anatomic-behavioral correlations between lesion sites and the two types of neglect, but it may be speculated that body-centered neglect of Patient 1 was more closely related to the anterior and medial extension of lesions than those of Patient 2, whereas the stimulus-centered neglect was more closely related to the lateral and posterior extension of the lesions than those of Patient 1. This locational difference is not inconsistent with the notion³³ that the right frontal lobe and its connections with basal ganglia subserve an exploratory-motor component of attention, whereas the right parietal lobe subserves the sensory-perceptual component of attention. To elucidate areas responsible for the dissociable functions, further data are needed for both behavioral and lesion analyses, regardless of which of the theories best explains the data.

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