ORIGINAL ARTICLE

Study on the Occurrence and Neural Bases of Hemispatial Neglect With Different Reference Frames

Yuehong Yue, MD, Weiqun Song, PhD, Su Huo, MD, Maobin Wang, MD

ABSTRACT. Yue Y, Song W, Huo S, Wang M. Study on the occurrence and neural bases of hemispatial neglect with different reference frames. Arch Phys Med Rehabil 2012;93: 156-62.

Objectives: To study the distributions and the neural correlates of left hemispatial neglect with different reference frames.

Design: Data were collected from patients with right brain injury who participated in a case series.

Setting: Hospital departments of rehabilitation and neurology.

Participants: Right brain-damaged patients (N=110).

Interventions: Not applicable.

Main Outcome Measures: The frequency of left hemispatial neglect with different reference frames was investigated, and the respective brain lesions were displayed and analyzed.

Results: Not all subjects finished predesigned neglect tests because of their condition: 8 of the 55 neglect patients were unable to complete the test for classification. Thirty (63.83%) of 47 subjects with neglect displayed both allocentric and egocentric neglect, while 17 subjects showed pure egocentric neglect. The lesions in the inferior frontal gyrus, precentral gyrus, postcentral gyrus, superior temporal gyrus (STG), middle temporal gyrus (MTG), insula, and surrounding white matters were more frequent in the neglect group than in the control group. Compared with the egocentric neglect group, the lesions in the right STG, MTG, lenticular nucleus, and the surrounding white matter were damaged more frequently in the group displaying both allocentric and egocentric neglect.

Conclusions: More than half of the subjects with left neglect after right brain injury have both egocentric and allocentric neglect. The right inferior frontal gyrus, precentral gyrus, postcentral gyrus, STG, MTG, insula, and the surrounding white matter are associated with left hemispatial neglect. Left allocentric neglect is associated with the right STG, MTG, and lenticular nucleus.

Key Words: Attention; Frontal lobe; Parietal lobe; Perceptual disorders; Rehabilitation; Temporal lobe.

HEMISPATIAL NEGLECT is a common syndrome that presents with behavioral abnormalities after unilateral brain injury, especially the right cerebral hemisphere. Patients with this syndrome often chronically face the ipsilesional side and do not orient to or respond to contralateral stimuli—"looking without seeing." This syndrome not only has a negative effect on daily life, but also has been regarded as a negative prognosis factor.[1-4] Illuminating the anatomical basis of this syndrome is important for understanding the functions of integrated brain structures, as well as for prescribing suitable rehabilitation programs and evaluating prognosis.

Which brain regions are responsible for hemispatial neglect? This has been an intensely controversial issue for neuropsychologists and some clinicians for more than 100 years. Earlier studies indicated that damage to the inferior parietal lobule (IPL) and temporal-parietal junction was more frequent in neglect patients.[5-7] However, some researchers have recently put emphasis on the importance of superior temporal gyrus (STG) for the emergence of hemispatial neglect.[8-10] In addition, basal ganglia, thalamus,[9] and the frontal lobule[11] lateralized in the right hemisphere were reported to be related to left hemispatial neglect.

Several factors other than the differences in design elements, for example sample sizes, inclusion criteria, lesion mapping methods, and so on, could explain these conflicting results. First, the variance is considerable in the localization and extent of lesions among neglect subjects. Next, it is widely accepted that hemispatial neglect is a heterogeneous syndrome.[12,13] Subjects with this syndrome manifest differently in clinical practice, mainly in the following ways: sense/motor dimensions,[14] sense modalities,[15] the size and position in space that is neglected, and reference frames.[16] Therefore, a study with a much bigger sample accompanied by a more specific classification of neglect would be more effective to understand the lesions related to hemispatial neglect.

According to reference frames, hemispatial (usually left) neglect could be divided into 2 groups, that is, left spatial neglect can be either egocentric or allocentric neglect. Subjects with egocentric neglect, also called viewer-centered neglect, often neglect items in the contralesional (ie, left) side relative to their own midline. With allocentric neglect, or stimulus-centered neglect, the space neglected is relative to the external object being viewed. Patients neglect the left side of the stimulus, irrespective of the location of the stimulus relative to them.[16,17] A review indicated that visual input could be com-

List of Abbreviations

BA	Brodmann area
IPL	inferior parietal lobule
MTG	middle temporal gyrus
STG	superior temporal gyrus

From the Department of Rehabilitation, Xuanwu Hospital, Capital Medical University (Yue, Song, Huo, Wang); Key Laboratory for Neurodegenerative Disease of Ministry of Education (Song); and the State Key Laboratory of Cognitive Neuroscience and Learning, Clinical Research and Rehabilitation Center of Cognitive Dysfunction (Song), Beijing, China.

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Correspondence to Weiqun Song, PhD, Dept of Rehabilitation, Xuanwu Hospital, Capital Medical University, NO.45, Changchun street, Xuanwu District, Beijing, China, 100053. e-mail: *zhaoyongboyueyue@163.com; songwq66@163.com*. Reprints are not available from the author.

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Table 1: Demographic and Clinical Data of the Neglect and Control Groups

Characteristics	Neglect	Controls
No.	55	55
Sex (W/M)	16/39	13/42
Age, mean±SD (y)	57.44±12.42	57.00±12.11
Etiology	44 infarct; 9 hemorrhage; 2 trauma	35 infarct; 20 hemorrhage
Education, mean±SD (y)	10.05±4.49	11.27±3.96
MMSE, mean±SD (scores)	23.82±3.87	27.84±2.57
Time since lesion, mean±SD (d)	27.07±29.93	20.00±37.86
Time of image, mean±SD (d)	23.91±35.68	16.00±36.50
Lesion volumes, mean±SD (cm^3)	19.61±17.01	3.67±3.66
Visual field deficit (%)	12.73	1.82
Facioplegia (%)	89.09	76.36
Contralesional dystonia (%)	32.72	54.55
Somatosensory deficit of contralesional side (pain, %)	38.18	96.43
Babinski sign (%)	94.55	74.55

NOTE. Muscle strength was scored with the clinical ordinal scale, where 0 is no trace of movement and 5 is normative movement. Mean and SD are given for age, MMSE, time since onset, time of image, lesion volume, and muscle strength of contralesional limbs.
Abbreviations: M, men; MMSE, scores in the Mini-Mental State Examination; W, women.

puted with different reference frames and processed in different brain neuronetworks.[18] However, fewer studies have investigated the neural basis of neglect with different reference frames, and those that exist have used relatively small sample sizes. Recently, some authors investigated a sample of 16 subjects with left spatial neglect and found that egocentric neglect is associated with the right STG, while allocentric neglect is associated with the right angular gyrus.[16] In the present study, with a larger sample, we tried to investigate subjects who had right hemisphere damage and analyzed pertinent brain regions associated with left spatial neglect with different reference frames. These efforts may further confirm the conclusions reached in the previous study.

METHODS

Participants

From June 2009 to September 2010, a series of 110 patients with right hemisphere damage from the departments of rehabilitation and neurology were recruited: 55 patients with hemispatial neglect (neglect group) and 55 subjects without hemispatial neglect (control group). Inclusion criteria included the following: right hemisphere lesions confirmed by brain computerized tomography or magnetic resonance imaging, consciousness, and the capability to understand and participate in this study. Exclusion criteria were the inability to remain conscious or cooperate in clinical examinations, multiple lesions on brain computed tomorgraphy or magnetic resonance images, and other neurologic or psychiatric conditions, which precluded participation in this study, such as dementia and severe depression.

All subjects gave informed consent for the study using methods and consent forms approved by the local ethics council. The vision of each recruited subject was normative or corrected to normative. Every patient in the control group was right-handed except for 1. In the neglect group, 53 cases were right-handed and 2 cases were left-handed.

The clinical characteristics of these 2 groups are shown in table 1. The 2 groups did not differ with respect to sex (χ^2_1=.42, P=.52), age (t_{108}=.19, P=.85), etiology (χ^2_2=5.52, P=.06), education level (t_{108}=–1.51, P=.14), time of scan (t_{108}=1.15, P=.25), time since onset (t_{108}=1.09, P=.28), frequency of contralesional facioplegia (χ^2_1=3.12, P=.08), or visual field deficit (continuity correction χ^2_1=3.37, P=.07), as well as frequency of contralesional paresthesia (χ^2_1=1.33, P=.25). In contrast, there were significant differences between the 2 groups in Mini-Mental State Examination scores (corrected $t_{93.74}$=1.33, P<.01), lesion volume (corrected $t_{58.98}$=6.79, P<.01), frequencies of contralesional dystonia (χ^2_1=5.32, P=.02), and Babinski sign ($\chi^2_{1=}$8.42, P=.00).

Neglect Testing

Some patients might manifest typical left spatial neglect symptoms. For example, patients faced to the ipsilesional side chronically, with their heads turning toward and eyes gazing at that side and the objects or people on their contralesional side often being omitted. Others might not be diagnosed as left spatial neglect by clinical observation, so all patients were grouped and assessed with the following 6 neglect tests.

1. Line bisection test: Five level lines with an equal vertical spacing were distributed on a horizontally oriented 295mm × 210mm A4 sheet of paper. The line lengths (L) were 16, 14, 12, 10, and 8cm long. Patients were asked to mark the midpoint of each line. The distances between the marked midpoints and the corresponding true midpoints were measured (R). A positive value indicated deviation toward the right of the true midpoint, while a negative value indicated deviation toward the left. The severity of neglect was calculated with the formula R/(L/2) ×100%.[19] If the final value calculated was beyond 12%, it would constitute a case of left spatial neglect.[20]
2. Line cancellation test: Thirty black lines (length 15–20mm, thickness 1mm) with various orientations were scattered on an A4 sheet of paper. The left and right side each contained 15 lines. The patients were asked to mark all the lines on the sheet. The assessment of neglect was according to the formula: 10×[(30–R–L)/30] ×[(R–L)/(R+L)] (R=the number of marked lines on the right side, L=the number of marked lines on the left side). In this formula, (30–R–L)/30 denoted the omission index, and (R–L)/(R+L) denoted the laterality index. The severity of neglect was calculated by multiplying the omission index by the laterality index, and then the product was normalized to a 10-point scale by multiplying by 10 for easy comparison. If the result was a positive value, it

Table 2: Performance of Left Neglect Patients in Tests for Neglect

Tests for Neglect	Nos. of Patients Being Tested	Performance of Neglect Patients: All Neglect Patients	Allocentric With Egocentric	Egocentric
Line cancellation	55	3.32±3.25	4.44±3.11	1.97±2.92
Line bisection	54	34.47±31.01	42.13±32.14	16.71±20.48
Star cancellation	45	4.99±3.37	6.10±2.80	3.27±3.56
Clock drawing	38	0.97±0.71	1.13±0.63	0.64±0.74
Scene copying	29	5.93±4.75	7.37±5.09	2.89±2.32
Gap detection—circles omitted	49	36.19±29.70	41.77±26.61	23.00±0.30
Gap detection—left gap detected incorrectly	49	24.41±33.95	0±0	24.41±33.95
Gap detection—right gap detected incorrectly	49	0±0	0±0	0±0

suggested neglect to the left; a negative value suggested neglect to the right. In addition, if the patients scribbled on the right side of the test paper without marking any line, the result would be 10. Conversely, if a scribble occurred on the left side, the result would be –10.[19]

3. Clock drawing: A clock was presented on an A4 sheet of test paper, with the hour hand and minute hand indicating 35 minutes past 1. Subjects were asked to copy the clock on the test paper. The drawing was scored with respect to the presence of contralesional omissions. When all items on the left side of the clock were omitted, scores were 2; when some items on the left of the clock were omitted or being distorted, scores were 1; zero indicated no omissions.[21]
4. Star cancellation: Small stars were scattered among big stars, letters, and words on an A4 test paper. The subjects were asked to mark the small stars. The number of small stars was equal on both sides of the paper (left or right: 27, middle: 2). The number of target stars marked on each side and in the middle were recorded as well as the percentages of small stars omitted out of all presented.[22]
5. Scene copying: On the test paper was a scene consisting of 4 objects: a house, a fence, and 2 trees. Subjects were asked to copy this scene. This picture comprised 8 symmetrical subobjects. Every subobject included 2 components (ie, 16 components within 8 subobjects): a left one and a right one, and 1 component being omitted or displaced was recorded as an error. The final scores were expressed in percentage terms (total errors/the number of components×100%).[16]
6. Gap detection: A series of 30 circles (diameter 15mm) was presented on the A4 test paper, with 15 on the left side and 15 on the right side. Twenty circles had gaps: 10 circles had 1 gap on the left side, and 10 circles had 1 gap on the right side. This test asked subjects to mark × on circles with gaps and mark ✓ on circles without gaps. Three values were recorded: the number of circles omitted on both sides, and the number of circles with left gaps or right gaps marked incorrectly, that is, the gaps being omitted. The final scores were expressed in percentages: circles omitted/total circles×100%, errors of left (right) gaps detection/circles with left (right) gaps marked×100%.[16]

The gap detection test was reportedly the most common test for distinguishing between allocentric neglect and egocentric neglect.[13,16,23] Finishing this test correctly requires that 1 notices all the circles and the gaps (either on the left or right). Take left hemispatial neglect for example. If the subject marked some circles on the right of the test paper correctly, but only neglected some circles on the left, this would be regarded as egocentric neglect. If the subject marked all the circles on the test paper, but incorrectly marked the circles with left gaps using ✓, that is neglecting gaps on the left of circles, and would be regarded as allocentric neglect. If the subject neglected both circles on the left of the test paper and gaps on the left of circles, this would be regarded as both egocentric and allocentric neglect.

While being tested, subjects were seated suitably, with test papers on the desks in front of them, aligned with their body midline. If patients manifested left spatial neglect in more than 1 test, then the subjects were attributed to the neglect group.

Neglect Classified According to Different Reference Frames

The neglect with different reference frames was distinguished according to performance on the gap detection test, which was also 1 of the tests used by Hillis et al[16] to distinguish the 2 types of neglect. If patients omitted the left/right gaps (ie, marking ✓ on circles with left/right gaps), and omission for left gaps was more significant than for right gaps, or if they omitted more than 10% of left gaps while correctly recognizing right gaps of circles that were marked, left allocentric neglect was diagnosed.[16,24,25] If patients neglected some circles on the left of the test paper, with other circles marked correctly, left egocentric neglect was diagnosed. The performance of the neglect group in the tests is shown in table 2.

Lesion Mapping and Analysis

With standard brain imaging protocols used clinically, 31 subjects completed computed tomography brain imaging, while 79 subjects completed magnetic resonance brain imaging (including diffusion-weighted, T1, T2-weighted magnetic resonance imaging). The lesions were mapped using the free MRIcro software[26,a] and were drawn manually on slices of a T1-weighted template magnetic resonance imaging scan from the Montreal Neurological Institute. This template is approximately oriented to match Talairach and Tournoux space[27] and is distributed by the MRIcro software.

We superposed the lesions of the neglect group and the controls. In order to find which structures were damaged more frequently in the neglect group than in the control group, the subtracted overlay plot was acquired by subtracting the lesions of the control group from those of the neglect group. Using the same method, we illustrated regions that were specifically damaged in allocentric neglect but spared in egocentric neglect.

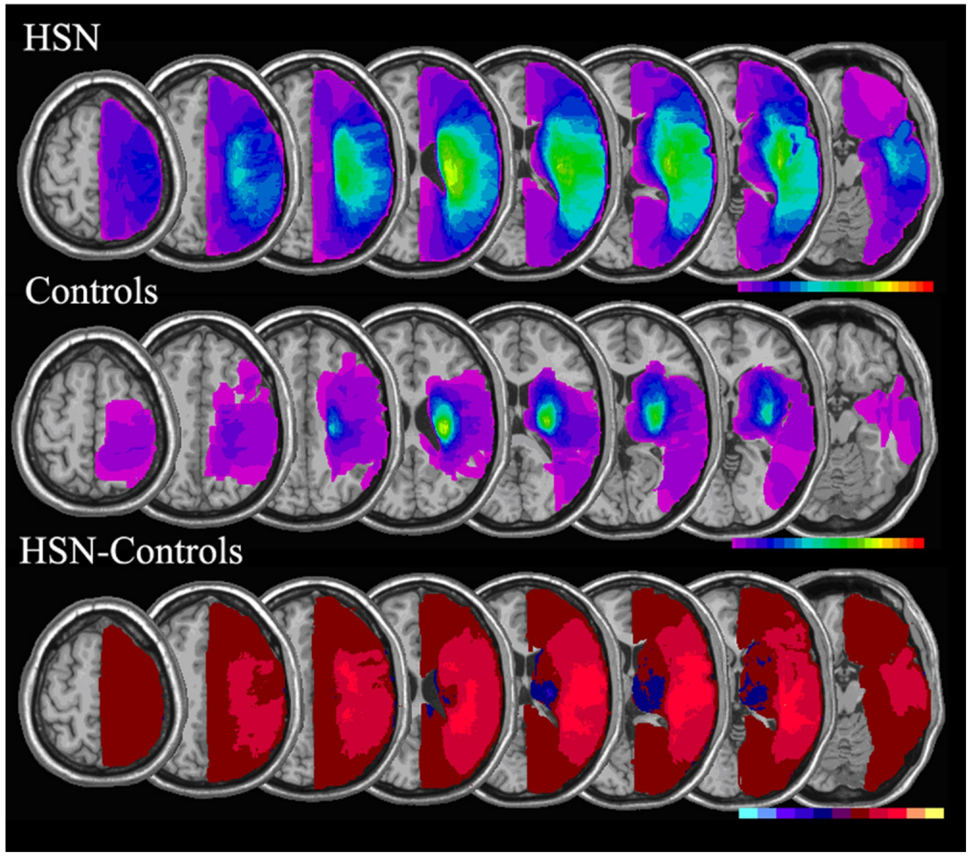

Fig 1. The overlay plots of lesions of the neglect and control groups. The upper 2 panels are the patients with left spatial neglect (n=55) and the patients with right brain damage without spatial neglect (controls; n=55), respectively. The number of overlapping lesions is illustrated by different colors from violet to red gradually increasingly: violet represents that regions are damaged in only 1 patient, and red represents that regions are damaged in all patients. The bottom panel represents the overlay plot of the subtracted overlay lesions of patients with spatial neglect minus the control group. The percentage of overlapping lesions of the neglect patients after subtracting controls are illustrated by 5 different colors from dark red (difference, 1%–20%) to white yellow (difference, 81%–100%). Each color represents 20% increments. Purple (the middle of the color bar) designates regions that are damaged in an equal percent in the 2 groups (difference, 0). The colors from dark blue to light blue indicate regions damaged more frequently in neglect patients than in controls.

RESULTS

Forty-seven out of 55 left spatial neglect patients completed the gap detection tests, while 8 of them did not because of poor condition (5 for new brain infarction, 3 for fatigue). Seventeen patients manifested pure egocentric neglect, while 30 (63.83%) showed both egocentric and allocentric neglect.

Subjects with combined egocentric and allocentric neglect demonstrated more severe neglect than those with pure egocentric neglect in all the neglect tasks: line cancellation (t_{45}=–2.67, P=.01), line bisection (corrected $t_{44.35}$=–3.29, P<.01), star cancellation (t_{43}=–2.95, P<.01), gap detection (t_{45}=–2.21, P=.03), clock drawing (t_{35}=–2.14, P<.05), and scene copying (corrected t_{26}=–3.20, P<0.01) (see table 2).

Figure 1 shows the lesion overlay plots of the neglect group and the control group, respectively, as well as the subtraction plot that illustrates the regions damaged more commonly in neglect patients. All voxels that were damaged in either the neglect group or the control group were analyzed with MRIcro software. Only voxels damaged with more than 40% difference between the 2 groups were associated with left spatial neglect.

From the subtraction plot, it can be seen that the inferior frontal lobule (Brodmann area 44 [BA44]), precentral gyrus (BA44, BA6), postcentral gyrus (BA40, BA43), STG (BA42, BA41, BA22), middle temporal gyrus (MTG) (BA21), insula (BA13), and the surrounding subcortical white matter, as well as the IPL subcortical white matter, were more frequently damaged in neglect patients and are therefore associated with the emergence of spatial neglect.

Figure 2 shows the overlay plots of lesions in the pure egocentric neglect subgroup and the subgroup displaying both egocentric and allocentric neglect. From the subtraction plot that was acquired by subtracting the lesions of the egocentric neglect patients from those of the patients with both egocentric and allocentric neglect, some regions damaged more commonly in allocentric neglect patients were recognized, mainly localized in the STG (BA22) (from x, 46; y, –17; z, 8 to x, 60; y, –58; z, 16). The overlay lesions extended to the MTG (BA21), lenticular nucleus, basal ganglia, and the surrounding white matter.

DISCUSSION

Compared with the Hillis et al study,[16] the present study used a larger sample size to investigate the distributions and neural correlates of left spatial neglect with different reference frames, and it revealed 2 interesting findings. First, all subjects with left spatial neglect recruited in the present study had egocentric neglect, with more than 60% combined with allocentric neglect, and no pure allocentric neglect was discovered. Second, regions associated with left spatial neglect included the inferior frontal lobule, precentral gyrus, postcentral gyrus, STG, MTG, insula, and the surrounding white matter as well as the IPL subcortical white matter. However, the STG and MTG were mainly associated with allocentric neglect.

It has been asserted in earlier studies that hemispatial neglect can be divided according to different reference frames.[16,17,23,24] However, the distribution of hemispatial neglect with different reference frames over the whole left spatial neglect population has been very unclear. Hillis[16] pointed out that left egocentric neglect was the most common type of neglect, but is not often combined with other types. They investigated 50 patients with acute right hemispheric isch-

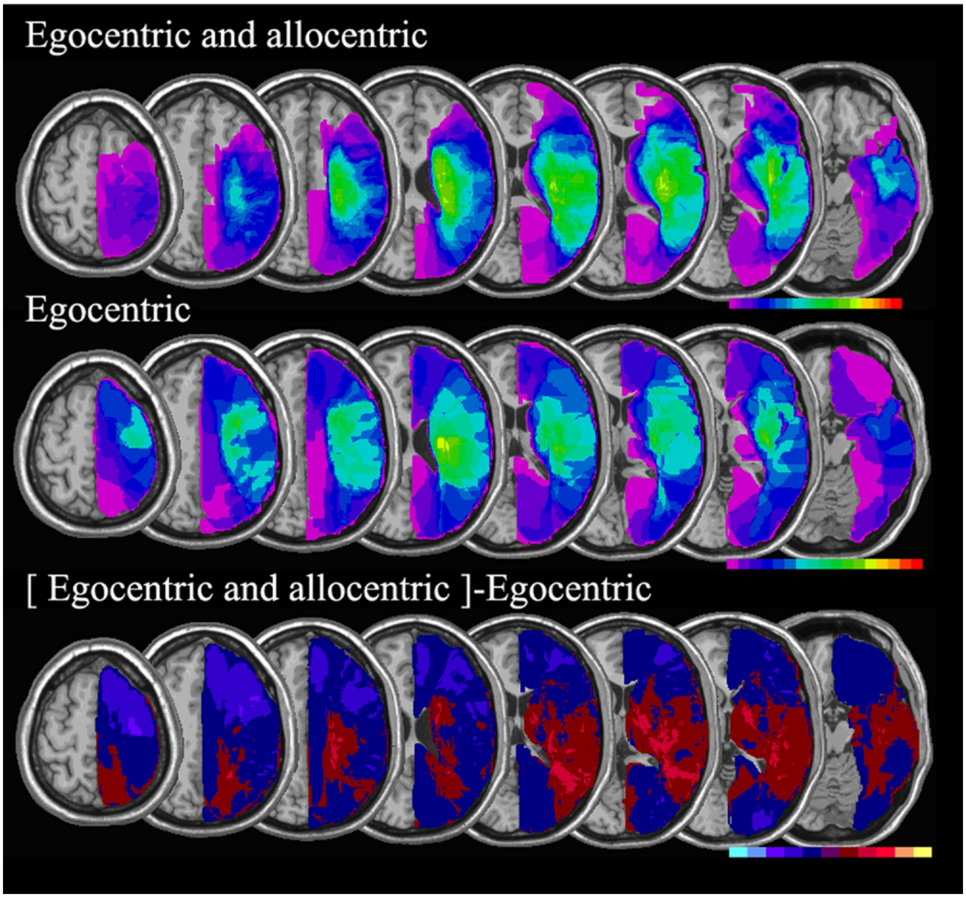

Fig 2. The overlay plots of lesions of the neglect and control groups. The upper 2 panels are overlay plots of lesions of patients with egocentric neglect (n=17) and of the patients with both allocentric and egocentric neglect (n=30), respectively. The bottom panel is the overlay plot of the subtracted overlay lesions of patients with both egocentric and allocentric neglect minus the patients with pure egocentric neglect.

emic stroke and found 11 patients with pure egocentric neglect, 4 with allocentric neglect, and 1 with both egocentric and allocentric neglect.[16] In the same way as the Hillis study, the present study also employed the gap detection test to distinguish the 2 types of neglect. However, with a larger sample size, the present study revealed that more than half the patients with left neglect were both egocentric and allocentric. The discrepancy between these studies could be attributed to several factors. First, patients with damage in the subcortex, cortex, or both were recruited in the present study, while only patients with damaged subcortical regions were recruited in the previous study. Second, it was more than 48 hours after onset when subjects were being tested in the present study, whereas the previous study tested within 48 hours. Hemispatial neglect occurs more commonly during the acute phase of stroke and lessens gradually during recovery.[28] Therefore, the results of the present study also indicated that egocentric neglect could be more transient, and patients with only subcortical lesions and pure egocentric neglect may recover more quickly than those with allocentric neglect, a hypothesis that needs to be confirmed in the future.

The present study indicated that allocentric neglect was related to the temporal lobule, especially the STG. Consistent with this, 1 previous study also found that left allocentric neglect was associated with hypoperfusion of the right STG (BA22).[16] This would be an interpretation for STG involvement in spatial neglect, as reported by Karnath et al.[10] The MTG was reported to be activated in visual perception for the localization of the object (allocentric spatial representation)[29] and may be associated with hemispatial neglect.[30] In addition, given the connection between the subcortical nucleus and superior temporal cortex, the basal ganglia could be associated with neglect, more accurately, with allocentric neglect. Some authors postulated that the right putamen, caudate nucleus, and STG composed the cortical-subcortical network for spatial perception and awareness,[8] especially for allocentric spatial representation indicated by the present study.

The representation of space in the human brain would need spatial maps in different reference frames. Spatial representation in allocentric and egocentric coordinates could subserve object recognition and intentional movement relative to the viewer, respectively.[17] Accordingly, spatial neglect with different reference frames would be dissociable theoretically. The premotor cortex and dorsal parietal lobe have been reported to be responsible for the egocentric spatial process,[31] and the ventral temporal-occipital cortex have been reported to be responsible for the allocentric spatial process.[32] These theories are consistent with our results.

The frontal-parietal network subserving endogenous attention or intentional attention[33] has been reported to be related to hemispatial neglect. Most research confirmed that the IPL, the angular gyrus of which may be responsible for egocentric spatial representation,[34] was crucial for the occurrence of hemispatial neglect.[5,35] Given the IPL subcortical white matter's contribution, egocentric neglect may be caused by the disconnection between the regions coding proprioception and somatosensory perception, such as the postcentral gyrus, and those coding the abstract, body-centered spatial representation, such as the IPL.[36] The motor cortex and premotor cortex in the frontal lobe have direct or indirect connections with the IPL. Studies with neural functional images showed that the right ventral premotor cortex was activated in computing spatial maps in the egocentric coordinate.[31,32]

The classification for this syndrome is not only important for understanding brain functions, but also significant for the rehabilitation setting. Prism adaptation has been reported to make improvement in pointing to the midline targets, which depended on the egocentric spatial representation. However, there was no improvement in selecting the smiling side of chimeric faces, which depended on allocentric (stimulus-centered) representation.[37] Consistent with that study, another study pointed out that the leftward between-object attentive deficit was ameliorated after prism adaptation.[38] This kind of attention shift, unlike within-object shift, requires crossing the object's borderline and the subject's midline. Therefore, it is not a stimulus-centered, but an egocentric representation. Other rehabilitation measures, such as transcranial magnetic stimulation with different parameters or regions stimulated,[39,40] may also have different effects on the neglect of different types.

Study Limitations

The present study also had some limitations. First, we did not take into consideration the amount of time since the lesion had formed. The severity of neglect may fluctuate, especially in the first week after a stroke; therefore, the epidemic features of neglect would be clearer if they were studied at different phases after onset. In addition, the brain images taken for clinical purposes that were used in this study showed the regions damaged structurally, but not those impaired only functionally. In theory, functional images could be more powerful in determining the regions responsible for neglect.

CONCLUSIONS

An increasing number of articles have revealed that hemispatial neglect is heterogeneous, not only in the diversity of clinical manifestations, but also in the dispersibility and variety of the associated lesions.[13] All subjects with left spatial neglect in the present study exhibited egocentric neglect, yet more than 60% of them had allocentric neglect simultaneously.

The present study revealed that the right inferior frontal lobule, precentral gyrus, postcentral gyrus, STG, and MTG were associated with left neglect, while the STG and MTG were related to allocentric neglect.

Hemispatial neglect is an adverse factor influencing the prognosis for patients with brain injury. Different rehabilitation methods could produce different effects for neglect of different types.[12,37] Accordingly, for patients with hemispatial neglect, it is more reasonable to determine the types of hemispatial neglect before prescribing suitable rehabilitation modalities.

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References

1. Appelros P, Karlsson GM, Seiger A, Nydevik I. Prognosis for patients with neglect and anosognosia with special reference to cognitive impairment. J Rehabil Med 2003;35:254-8.
2. Appelros P, Karlsson GM, Seiger A, Nydevik I. Neglect and anosognosia after first-ever stroke: incidence and relationship to disability. J Rehabil Med 2002;34:215-20.
3. Kalra L, Perez I, Gupta S, Wittink M. The influence of visual neglect on stroke rehabilitation. Stroke 1997;28:1386-91.
4. Cumming TB, Plummer-D'Amato P, Linden T, Bernhardt J. Hemispatial neglect and rehabilitation in acute stroke. Arch Phys Med Rehabil 2009;90:1931-6.
5. Vallar G, Perani D. The anatomy of unilateral neglect after right-hemisphere stroke lesions. A clinical/CT-scan correlation study in man. Neuropsychologia 1986;24:609-22.
6. Heilman KM, Watson RT, Bower D, Valenstein E. [Right hemisphere dominance for attention] [French]. Rev Neurol (Paris) 1983;139:15-7.
7. Driver J, Mattingley JB. Parietal neglect and visual awareness. Nat Neurosci 1998;1:17-22.
8. Karnath HO, Ferber S, Himmelbach M. Spatial awareness is a function of the temporal not the posterior parietal lobe. Nature 2001;411:950-3.
9. Karnath HO, Himmelbach M, Rorden C. The subcortical anatomy of human spatial neglect: putamen, caudate nucleus and pulvinar. Brain 2002;125:350-60.
10. Karnath HO, Fruhmann Berger M, Kuker W, Rorden C. The anatomy of spatial neglect based on voxelwise statistical analysis: a study of 140 patients. Cereb Cortex 2004;14:1164-72.
11. Husain M, Kennard C. Visual neglect associated with frontal lobe infarction. J Neurol 1996;243:652-7.
12. Hillis AE. Rehabilitation of unilateral spatial neglect: new insights from magnetic resonance perfusion imaging. Arch Phys Med Rehabil 2006;87(12 Suppl 2):S43-9.
13. Verdon V, Schwartz S, Lovblad KO, Hauert CA, Vuilleumier P. Neuroanatomy of hemispatial neglect and its functional components: a study using voxel-based lesion-symptom mapping. Brain 2009;133:880-94.
14. Sapir A, Kaplan JB, He BJ, Corbetta M. Anatomical correlates of directional hypokinesia in patients with hemispatial neglect. J Neurosci 2007;27:4045-51.
15. Vallar G. Extrapersonal visual unilateral spatial neglect and its neuroanatomy. Neuroimage 2001;14:S52-8.
16. Hillis AE, Newhart M, Heidler J, Barker PB, Herskovits EH, Degaonkar M. Anatomy of spatial attention: insights from perfusion imaging and hemispatial neglect in acute stroke. J Neurosci 2005;25:3161-7.
17. Hillis AE. Neurobiology of unilateral spatial neglect. Neuroscientist 2006;12:153-63.
18. Creem SH, Proffitt DR. Defining the cortical visual systems: "what", "where", and "how". Acta Psychol (Amst) 2001;107: 43-68.
19. Lee BH, Kang SJ, Park JM, et al. The Character-line Bisection Task: a new test for hemispatial neglect. Neuropsychologia 2004; 42:1715-24.
20. Sarri M, Greenwood R, Kalra L, Papps B, Husain M, Driver J. Prism adaptation aftereffects in stroke patients with spatial neglect: pathological effects on subjective straight ahead but not visual open-loop pointing. Neuropsychologia 2008;46:1069-80.
21. Golay L, Schnider A, Ptak R. Cortical and subcortical anatomy of chronic spatial neglect following vascular damage. Behav Brain Funct 2008;4:43.
22. Grimsen C, Hildebrandt H, Fahle M. Dissociation of egocentric and allocentric coding of space in visual search after right middle cerebral artery stroke. Neuropsychologia 2008;46:902-14.
23. Ota H, Fujii T, Tabuchi M, Sato K, Saito J, Yamadori A. Different spatial processing for stimulus-centered and body-centered representations. Neurology 2003;60:1846-8.
24. Marsh EB, Hillis AE. Dissociation between egocentric and allocentric visuospatial and tactile neglect in acute stroke. Cortex 2008;44:1215-20.
25. Kleinman JT, Newhart M, Davis C, Heidler-Gary J, Gottesman RF, Hillis AE. Right hemispatial neglect: frequency and characterization following acute left hemisphere stroke. Brain Cogn 2007;64:50-9.

26. Rorden C, Brett M. Stereotaxic display of brain lesions. Behav Neurol 2000;12:191-200.
27. Talairach J, Tournoux P. Co-planar stersotaxic atlas of the human brain: 3-dimensional proportional system - an approach to cerebral imaging. New York: Thieme; 1988.
28. Ringman JM, Saver JL, Woolson RF, Clarke WR, Adams HP. Frequency, risk factors, anatomy, and course of unilateral neglect in an acute stroke cohort. Neurology 2004;63:468-74.
29. Lee BH, Kang E, Cho SS, et al. Neural correlates of hemispatial neglect: a voxel-based SPECT study. Cerebrovasc Dis 2010;30: 573-83.
30. Fischer J, Spotswood N, Whitney D. The emergence of perceived position in the visual system. J Cogn Neurosci 2011;23:119-36.
31. Galati G, Lobel E, Vallar G, Berthoz A, Pizzamiglio L, Le Bihan D. The neural basis of egocentric and allocentric coding of space in humans: a functional magnetic resonance study. Exp Brain Res 2000;133:156-64.
32. Galati G, Committeri G, Sanes JN, Pizzamiglio L. Spatial coding of visual and somatic sensory information in body-centred coordinates. Eur J Neurosci 2001;14:737-46.
33. Corbetta M, Shulman GL. Control of goal-directed and stimulus-driven attention in the brain. Nat Rev Neurosci 2002;3:201-15.
34. Vallar G, Lobel E, Galati G, Berthoz A, Pizzamiglio L, Le Bihan D. A fronto-parietal system for computing the egocentric spatial frame of reference in humans. Exp Brain Res 1999;124:281-6.
35. Mort DJ, Malhotra P, Mannan SK, et al. The anatomy of visual neglect. Brain 2003;126:1986-97.
36. Committeri G, Pitzalis S, Galati G, et al. Neural bases of personal and extrapersonal neglect in humans. Brain 2007;130:431-41.
37. Ferber S, Danckert J, Joanisse M, Goltz HC, Goodale MA. Eye movements tell only half the story. Neurology 2003;60:1826-9.
38. Schindler I, McIntosh RD, Cassidy TP, et al. The disengage deficit in hemispatial neglect is restricted to between-object shifts and is abolished by prism adaptation. Exp Brain Res 2009;192:499-510.
39. Song W, Du B, Xu Q, Hu J, Wang M, Luo Y. Low-frequency transcranial magnetic stimulation for visual spatial neglect: a pilot study. J Rehabil Med 2009;41:162-5.
40. Nyffeler T, Cazzoli D, Hess CW, Muri RM. One session of repeated parietal theta burst stimulation trains induces long-lasting improvement of visual neglect. Stroke 2009;40:2791-6.

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a. Available at: http://www.mricro.com.