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著者	Nakatani Ken, Notoya Masako, Sunahara Nobuyuki, Takahashi Shusuke, Inoue Katsumi
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Ken Nakatani[a, b], Masako Notoya[c], Nobuyuki Sunahara[d], Shusuke Takahashi[e], Katsumi Inoue[c]

[a]Section of Communication Disorders, Faculty of Health Care Sciences, Himeji Dokkyo University, 7-2-1 Kami-ono, Himeji, Hyogo 670-8524, JAPAN

[b]Graduate School of Medical Sciences, Kanazawa University, 5-11-80 Kodatsuno, Kanazawa, Ishikawa 920-0942, JAPAN

[c]School of Health Sciences, College of Medical, Pharmaceutical and Health Sciences, Kanazawa University, 5-11-80 Kodatsuno, Kanazawa, Ishikawa 920-0942, JAPAN

[d]Department of Occupational Therapy, Koshi Rehabilitation Hospital 36 Shimoiino, Toyama, Toyama 931-8443, JAPAN

[e]Department of Physical Therapy, Takarazuka University of Medical and Health Care 1 Midorigaoka, Hanayashiki, Takarazuka, Hyogo 666-0162, JAPAN

Author email addresses:

Ken Nakatani: ken-n@himeji-du.ac.jp

Masako Notoya: notoya@mhs.mp.kanazawa-u.ac.jp

Nobuyuki Sunahara: sunahara@koshi-rehabili.or.jp

Shusuke Takahashi: hidenori@tumh.ac.jp

Katsumi Inoue: katsumi1@kenroku.kanazawa-u.ac.jp

Corresponding author:

Ken Nakatani

Section of Communication Disorders, Faculty of Health Care Sciences, Himeji

Dokkyo University, 7-2-1 Kami-ono, Himeji, Hyogo 670-8524, JAPAN

Email: ken-n@himeji-du.ac.jp

Telephone: +81-79-223-9027

Fax number: +81-79-297-0733

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Abstract:

In this study, we investigated the horizontal visual search ability and pattern of horizontal visual search in a large space performed by patients with unilateral spatial neglect (USN). Subjects included 9 patients with right hemisphere damage caused by cerebrovascular disease showing left USN, 9 patients with right hemisphere damage but no USN, and 6 age-matched healthy individuals with no history of brain damage. The number of visual search tasks accomplished was recorded in the first experiment, and the neck rotation angle was continuously measured during the task, and quantitative data of the measurements were collected. The results revealed a strong correlation between the number of visual search tasks accomplished and the total Behavioral Inattention Test Conventional Subtest (BITC) score in subjects with right hemisphere damage. In both USN and control groups, the head position during the visual search task showed a balanced bell-shaped distribution from the central point on the field to the left and right sides. Our results indicate that compensatory strategies along with the cervical rotation may be effective to improve the search ability and achieve balance towards the neglected side.

Keywords: unilateral spatial neglect, visual exploration, behavioral inattention test, head position, head turning

1. Introduction

Spatial neglect syndrome in patients with a cerebral lesion is defined as the failure to orient, report, or respond to relevant visual stimuli contralateral to the lesion.[1] In clinical practice, a desk-based test in a small space is frequently used to evaluate the severity of unilateral spatial neglect (USN). Several studies have investigated symptoms of spatial neglect, including non-left-to-right symptoms such as vertical neglect[2,3] and peripersonal/extrapersonal neglect.[3-5] The diversity of the neglect symptoms revealed by these studies have raised concerns regarding the discrepancies between the severities of USN as assessed by a desk-based test carried out in a small field versus those assessed using a large field. Rehabilitation programs for patients with USN often incorporate neck rotation and head turning to improve awareness of the neglected side. A technique for shifting the subjective midline towards the neglected side was developed by applying vibration to the dorsal neck muscles of the left side, which provided a motion sensation.[6-8] Understanding the visual search pattern of patients with USN performing a continuous task in a large field is important for developing an effective rehabilitation program for left-sided exploration.

A method for measuring the maximum angle of head rotation in a single-shot task has been developed using a goniometer. However, few studies have performed continuous measurement of the head rotation angle during a continuous task or evaluated the visual search pattern in patients with USN. In the present study, we used a flexible-angle sensor with mechanoelectrical transduction to evaluate the head rotation angle in response to continuous visual stimuli in a large field.

In this study, we aimed to correlate the number of tasks accomplished by patients with USN during a continuous visual search task in a large field and on a desk-based USN test. Further, we continuously measured the neck rotation angle in the plane in patients with USN while they performed a continuous visual search task in a large field. Further, the search pattern and head-turning efficacy were investigated.

We hope that results of this study will improve the understanding of USN and, in turn, aid the development of effective rehabilitation programs.

2. Methods

2.1. Participants

This study included 9 patients with right hemisphere damage caused by cerebrovascular disease with left USN (USN group, mean age: 71.9 ± 12.2 years), 9 patients with right hemisphere damage but without USN (non-USN group, mean age: 68.9 ± 12.0 years), and 6 healthy individuals with no history of brain damage (healthy adult group, mean age 69.0 ± 2.1 years) who were age-matched to the right hemisphere damage groups. Characteristics of subjects in the USN group are presented in Table 1. All the subjects were right-handed, had no cervical rotation disabilities or neurological deficits. Those with eye movement paralysis or visual field defects were excluded from the study. A Mini Mental State Examination (MMSE) was performed in order to exclude individuals with disturbance of consciousness, dementia, and severe attention deficits, and only subjects who scored above the cutoff point were included in the study. Before starting the visual search test, subjects were shown the shapes used in the task and instructed to identify and speak out the name of each shape to ensure that there were no disabilities in speech, vision, and cognition. All subjects with right hemisphere damage underwent a Behavioral Inattention Test Conventional Subtest (BITC, Japanese edition). Patients who scored below the cut-off point (131) on this test were classified as having USN. The mean BITC score of the USN group was 101 ± 34.8. The interval from the onset of USN to the date of the survey was 114 ± 50 days. Brain lesion types were identified using computed tomography (CT) and magnetic resonance imaging (MRI). The absence of USN in the healthy adult group was confirmed using line bisection and cancellation tests.

The study participants were given a complete explanation of the study, and only those who provided informed consents were included in the study. This study was approved by the Ethics Committee of Kanazawa University.

2.2. Procedure

The subjects were tested for horizontal visual search ability over a large field. As a part of this test, the number of visual search tasks accomplished was recorded, the neck rotation angle was continuously measured on the horizontal plane during the visual search task, and quantitative data were collected.

2.2.1. Settings and stimuli

The subjects were placed in a chair 1.5 m away from the display screen (170 cm high × 240 cm wide). The chair was positioned at the mid-sagittal part of the screen. The subject was positioned close to the screen, so that head turning and/or eye movements were necessary to accomplish the visual search task (Figure 1). The task was designed so that it was difficult for the subject to use eye movements alone to perform the visual search. The visual stimuli comprised shapes that were horizontally displayed in random order (Takara Co). The target shapes used for the task were easily identifiable and simple shapes such as circles, triangles, and cubes. Each set consisted of continuous display of 18 shapes, where each shape was displayed for 3.5 s. The time taken to display each set was approximately 1 min 10 s. The screen was bisected vertically into 2 halves (left and right) and 3 vertical zones were created on each side, yielding a total of 6 zones. The zones from the far left of the field to the center were named left 3 (L3), left 2 (L2), and left 1 (L1). The zones from the far right of the field to the center were named right 3 (R3), right 2 (R2), and right 1 (R1) (Figure 2). These 6 zones were assigned only for the purpose of obtaining data and were not displayed on the screen. During the interval between tasks, a red circle was displayed at the center of the screen. The room was dimly illuminated and an ultra-short focus model LCD projector (XP-50, SANYO Co.) was used to project the sets on the screen.

The cervical rotation angle was measured using a rotary potentiometer (DI-Angle rotator, Hikari Bellcom Co.). By using an electronic tool to measure the joint angle, we were able to continuously measure the rotation angle throughout the task, even during movement. The tool was equipped with a built-in light angle sensor, and the movable arm of the elastic body allowed it to adapt to various movements. The DI-Angle comprised an angle gauge, digital display device, and an analog-to-digital converter. The device recorded the perceived angle every 20 ms. The cervical rotation angle was continuously measured using software for angle analysis, and the data were processed using Microsoft Excel. The movable arm of the DI-Angle was fixed to the occiput using a flexible band. The subjectôs head could be moved freely. Since it weighed only 120 g, it was very light, and the subjects of a preliminary experiment reported no discomfort in movement while using the device.

2.3. Data analysis

The results of the 2 data sets were used for analysis.

2.3.1. Number of tasks accomplished during the horizontal visual search

The task was displayed horizontally in random order on the display screen. The subject was allowed to visually explore the field and was instructed to identify the observed shapes as quickly as possible. The observer recorded the responses, determined the wrong answers, and calculated the total number of tasks accomplished.

2.3.2. Continuous measurement of the cervical rotation angle and search pattern during the task

The cervical rotation angle of the subject during experiment 1 was continuously measured using a DI-Angle rotator. The subject was seated facing the center of the screen. The backrest of the chair was positioned parallel to the screen, and the subjectôs back and shoulders were placed against the backrest. The subject observed the red circle at the center of the screen; this was considered to be the initial head position.

Statistical analysis was carried out using SPSS 19 (IBM Co). The *t* test and a correlation study were conducted, and the level of significance was set at $P < 0.05$.

3. Results

3.1 Number of tasks accomplished during the horizontal visual search

All the subjects with right hemisphere damage underwent a desk-based BITC. In clinical practice, BITC is commonly used to determine the presence and severity of USN in patients with right hemisphere damage. The subjects with right hemisphere damage were grouped into the USN and non-USN groups based on their total BITC score. The mean BITC score of the non-USN group was 143 ± 4.1. Subjects with left USN, as identified by the BITC, exhibited a pronounced neglect of the left side when tested with a visual search task in a large space (Table 2). In contrast, the non-USN and healthy adult groups were able to respond to all the questions from the visual search task. Simple regression analysis revealed a strong correlation between the number of visual search tasks accomplished in the large field and the total BITC score in subjects with right hemisphere damage ($r = 0.793$, $P < 0.01$). There was no evidence of ipsilateral neglect using a visual search task in a large space or the desk-based test.

3.2. Continuous measurement of the cervical rotation angle and search pattern during the task

The subjects were divided into the USN and control groups (non-USN and healthy control groups) based on the presence or absence of USN. Figure 3 illustrates the position of the head during the visual search task. The X-axis represents the degree of horizontal movement, where the position of the neck was 0° when the head was directed towards the center of the screen. Five-degree increments were used for horizontal movements to either side of the center, where a rightward shift from the central point was considered positive and a leftward shift was considered negative. The Y-axis represents the percentage of time in each head position used during the task. The head position for the entire duration of the task is equal to 100%.

In the control group, the head position during the visual search task showed a balanced bell-shaped distribution from the center point to the left and right sides. Subjects with USN showed a wider bell-shaped distribution to left and right sides. Table 3 shows the cervical rotation angle as well as the average and maximum values of both groups. The *t* test analysis revealed no significant difference between the USN and control groups. Further, a *t* test in the USN group (n = 9) comparing the average and maximum points of cervical rotation angle between the left and right sides did not reveal significant differences.

There was no correlation between the cervical rotation angle and the number of accomplished tasks during the horizontal visual search between the 2 groups. In the left USN group, there was no correlation between the number of accomplished tasks and the left-sided rotation angle.

The number of accomplished tasks, total points from L1ïL3, and total points from the BITC were compared between the USN and control groups. As per the F test, the data were not normally distributed. A Wilcoxonôs rank sum test was conducted and significant differences were found between the groups for the number of accomplished tasks ($P < 0.01$) and for total points at L3 ($P < 0.01$), L2 ($P < 0.01$), L1 ($P < 0.05$), and from the BITC ($P < 0.01$). As mentioned previously, a *t* test comparing the cervical rotation angle between groups did not reveal significant differences.

4. Discussion

4.1. Evaluation of USN using a visual search task in a large space and a desk-based test

Typical desk-based tests are performed in a downward-facing posture in a small space. However, in daily life, recognition of people or obstacles while standing or sitting requires a forward-facing posture in a larger space. This requires good visual space perception. In order to understand the visual space perception of subjects with USN, it is important to evaluate the severity of USN in a similar setting that reflects the conditions of daily life.

Results from the present study identified a strong correlation between the visual search ability in a large space and the performance on a desk-based test carried out in a limited space. This suggests that the BITC score can can be used to predict the visual search ability in a large space conducted with the subjects in a forward-facing posture. However, there are significant differences between the testing environment and daily life in terms of dimensionality (two-dimensional versus three-dimensional) and conditions (static versus dynamic). Moreover, the visual search task in this study was performed only in the horizontal plane. The results of this study may not directly imply that the BITC score could be used to interpret the severity of USN in a setting that reflects the conditions of daily life.. The number of subjects in this study was low and this is a pilot study. Future studies with a larger study population would give us a clearer understanding.

In the present study, contralateral neglect was found in the large space test as well as the desk-based test; however, extreme ipsilateral neglect was not found (Table 2). Thus, neither test used in the present study identified any differences in the direction (area) of neglect.

4.2. Analysis of cervical rotation angle in the horizontal plane and search pattern in a large space

The present study succeeded in evaluating the search patterns employed by patients with USN by continuously measuring the cervical rotation angle in horizontally oriented tasks. The neck and head were not fixated, and the DI-Angle device, which allows unrestricted head movement, was affixed to the subjectsô neck. Therefore, it was possible to observe the subjectsô natural horizontal search pattern.

We analyzed the horizontal visual search pattern in a large space. Both the USN and control groups showed a bell-shaped distribution (Figure 3), suggesting nearly equal left- and right-sided visual search patterns. Karnath, Niemeier, & Dichgans[9] analyzed the gaze and head movements of subjects with USN by evaluating the visual search pattern for randomly displayed letters in a sphere with an inner diameter of 190 cm. They found the search patterns of both the USN and control groups had a bell-shaped distribution. Their results are in conflict with those of Kinsbourne,[10,11] who suggested that there was a stepwise increase in the awareness of the ipsilateral side. In addition, it was understood that eye and head movements were shifted to the right during visual search, and search of the entire frame shifted towards the ipsilateral side. In the present study, the head position during horizontal visual search in the large field exhibited a bell-shaped distribution. Among the USN group, there was no significant difference in the head position between the left and right sides. Accordingly, in the present test environment, we did not find any statistically significant ipsilateral shift in the USN group. It is generally accepted that USN patients turn their heads towards the side ipsilateral to the lesion. ~~Since~~ The data from the present study demonstrated a bell-shaped distribution and did not find strong ipsilateral shift.

Second, we analyzed the correlation between the horizontal visual search pattern in a large space and the number of accomplished tasks. There was no correlation between the number of accomplished tasks during visual search and the cervical rotation angle. This was true even when the USN group was analyzed alone, suggesting that the cervical rotation angle and range were not directly affected by visual search in a large space. Therefore, the test parameters used in the present study may provide information on factors other than cervical rotation that influence visual search.

As shown in Table 3, there was no significant difference in left-to-right cervical rotation or in the maximum values between the USN and control groups. Both groups exhibited a similar range of visual search in a large space. However, as shown in Table 2, there were significant differences in the visual search of the left side of the screen (L3, L2, and L1).

In this case, we assumed that eye scanning might contribute to the difference in visual search ability. Although both groups displayed a similar range of head positions, the control group was able to search the left side by eye scanning. However, because the USN group was not able to search the left side, they may have been unable to recognize the displayed task. Because the USN group performed well on the right side, they were capable of right-sided eye scanning. However, since an eye camera was not used in this study, it is possible that the head position and the direction of gaze were not the same. Accordingly, further studies that measure the eye movements will be necessary to explore these findings. Karnath et al.[9] reported that during spontaneous search, subjects with USN showed a deviation of gaze, head position, and eye-in-head position towards the ipsilateral side. They also reported that the subjects with USN had a similar range as the control subjects when asked to look at both the left and right sides. A cueing procedure has been suggested as a method to reduce symptoms of neglect symptoms. It may not be possible to directly refer to the results of Karnath et al.,[9] but the results from our study demonstrate that subjects with USN might suffer from a reduction in voluntary visual scanning of the neglected side during visual search in a large space. Consciously scanning the left side, which may reduce neglect symptoms, is suggested as a method for improving visual search of the neglected side in patients with USN.

It has been suggested that setting the subjective midline at the midline or shifting it to the neglected side can improve the left-sided visual perception in patients with USN.[6,12] In this study, we try to investigate the cervical rotation pattern of the patients with left space USN, and the results indicated the bell-shape. We observed that the patients with left space USN rotated their head to the neglected side. However, the number of visual search tasks accomplished in the neglected side was quite low. To augment their conscious visual search range to the neglected side, it may be effective to not only use the head turning to the neglected side, but also combining it with other compensatory strategies, for instance, visual scanning and trunk rotation.

4.3. Conclusion and future directions

Clinicians and researchers have reported the types of neglect symptoms, and have debated the correlations between the desk-based tests and activities in daily life, and the efficacy of cervical rotation among patients with USN. However, many areas of investigation remain to be explored. The quantitative data in this study provide a better understanding of the symptoms in patients with USN.

Further studies investigating the efficacy of training programs for subjects with USN are necessary to enhance our understanding of USN syndromes and serve as an important reference for effective rehabilitation programs.

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Figure legends

Figure 1. Illustration of the visual search task in a large space

Figure 2. The numbered areas on the screen. The screen is divided vertically into 6 areas for data processing. L: left, R: right.

Figure 3. Head position during the visual search task in a large space (%). Subjects were divided into 2 groups based on the presence or absence of USN. Controls include subjects with left hemisphere damage without USN and healthy subjects. The solid line indicates the data of the controls, the dotted line indicates that of the patients with USN. The X-axis is grouped into 5-degrees increments; 0 degrees is located at the center of the screen. A shift to the right was regarded as positive, whereas a shift to the left was regarded as negative. The Y-axis is the percentage of the head position during the visual search task. The head position over the course of the entire time was considered 100%.(USN: unilateral spatial neglect)

Figure 1

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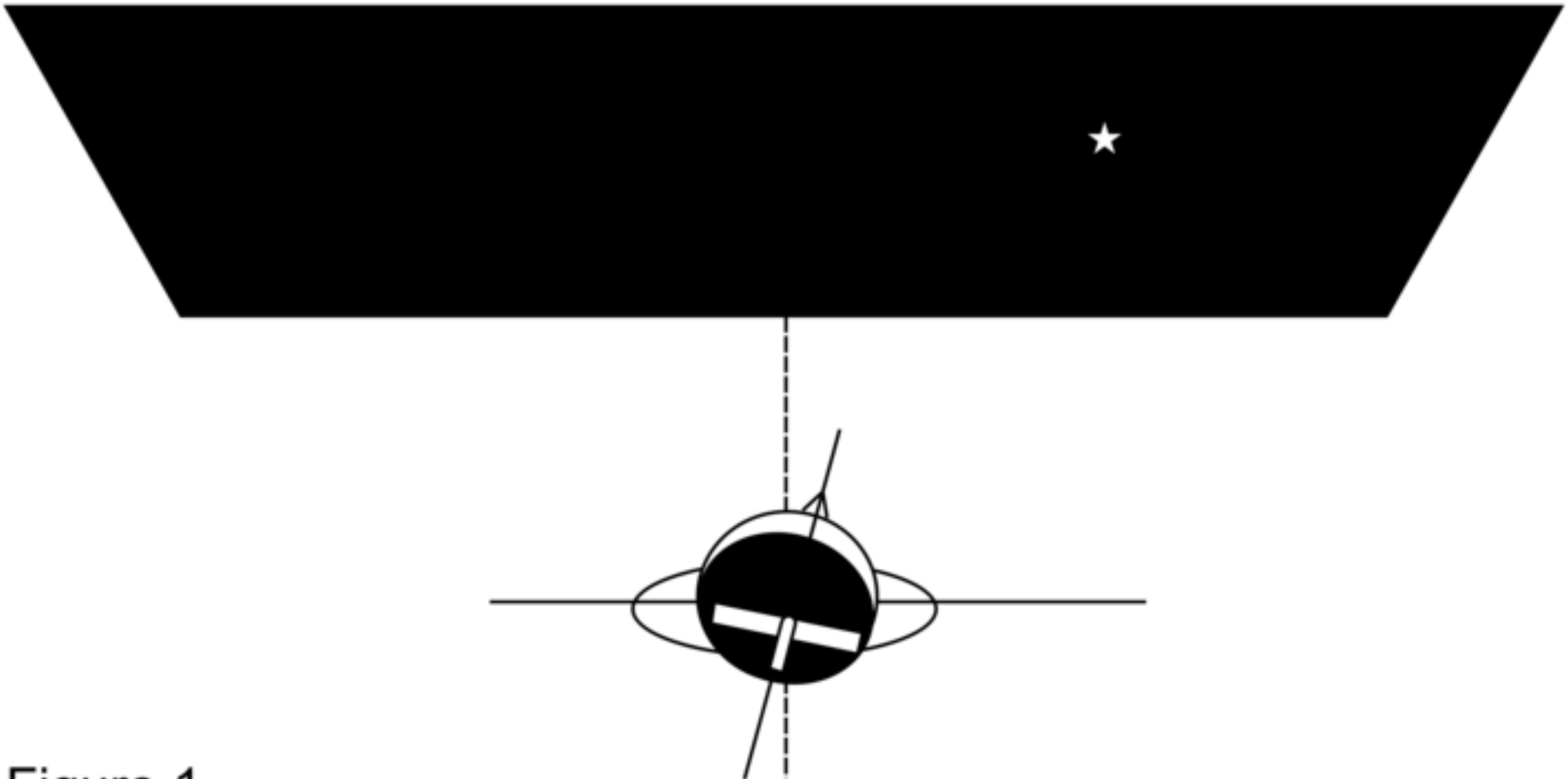

Figure 1

Figure 2
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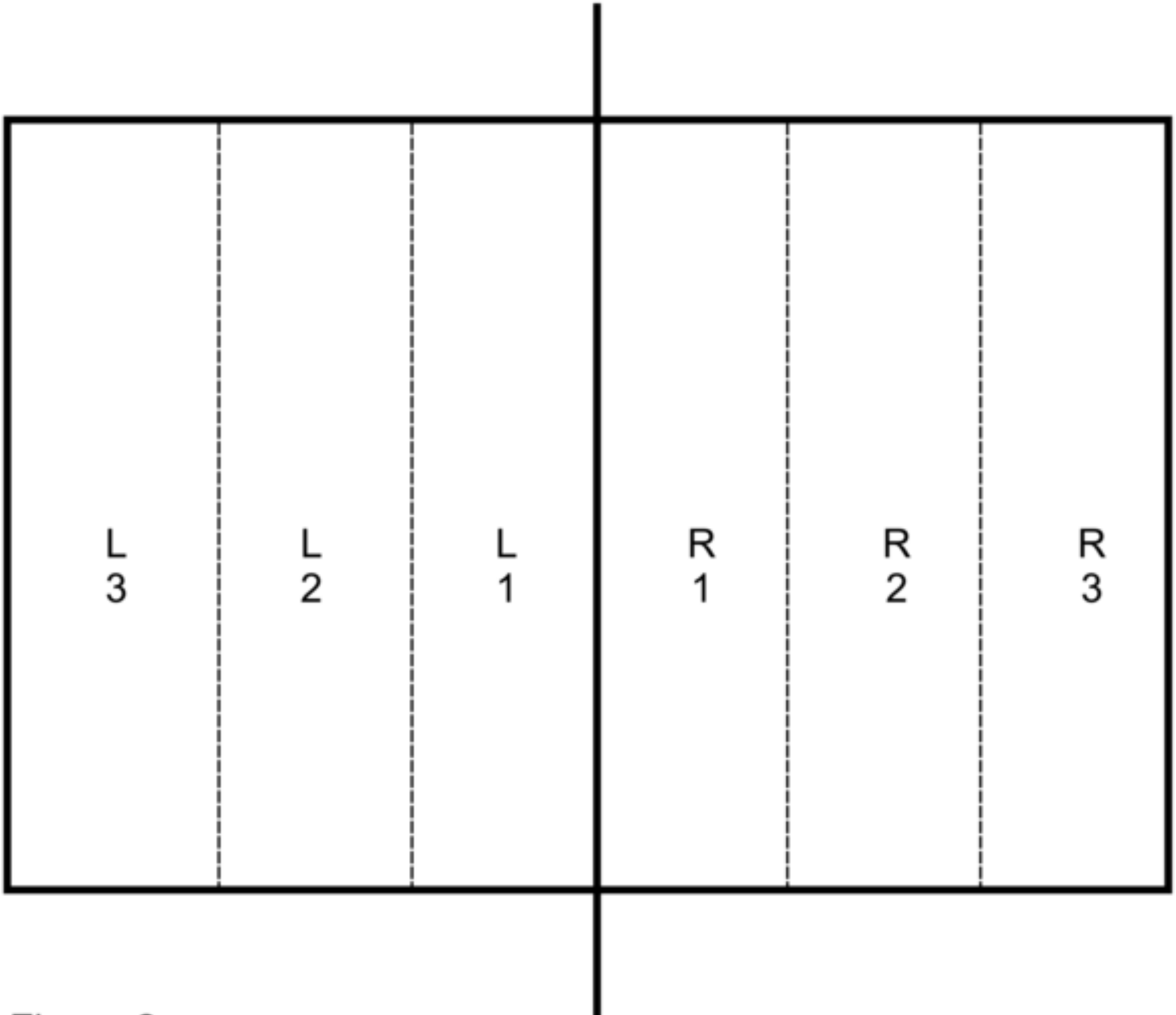

Figure 2

Figure 3
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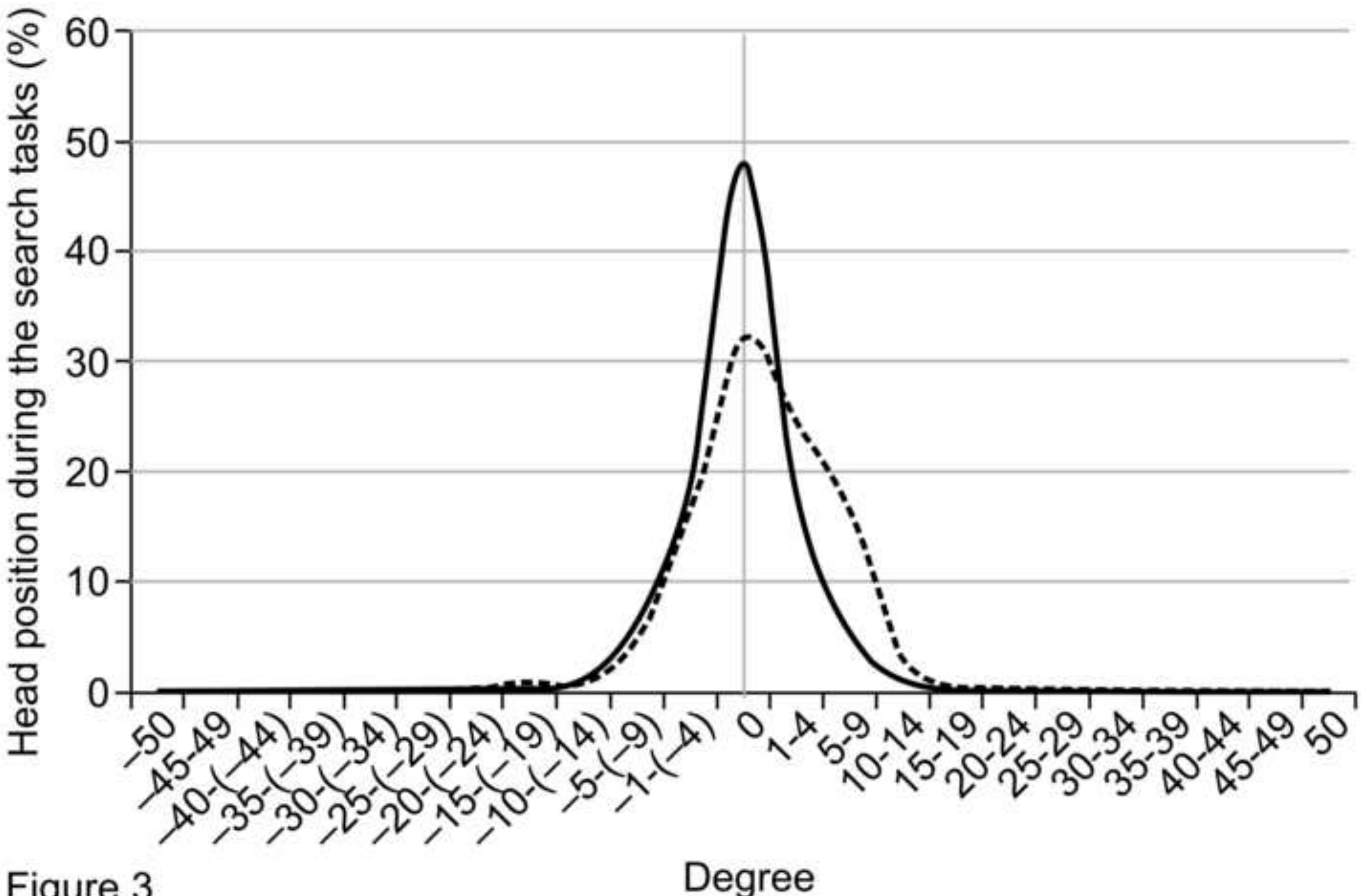

Figure 3

Table 1. Demographic and clinical characteristics of patients with USN

Patient	Sex	Age (years)	Cause of USN	Lesion location	Days since onset	Hemianopia	BITC[§] score
							Total Score*
1	F	79	Infarction	Parieto-occipital	37	No	35
2	M	59	Hemorrhage	Putamen	135	No	100
3	M	73	Infarction	Frontal	164	No	130
4	F	85	Hemorrhage	Thalamus	70	No	49
5	M	78	Hemorrhage	Temporo-occipital	106	No	111
6	M	80	Aneurysm	Temporal	161	No	114
7	M	46	Hemorrhage	Putamen	56	No	117
8	F	70	Hemorrhage	Putamen	173	No	128
9	F	77	Infarction	Parietal	126	No	123

[§]BITC = Behavioral Inattention Test Conventional subtest (Japanese edition), *maximum score = 146

Table 2. Average scores of the visual search task in a large field.

	Total	L3	L2	L1	R1	R2	R3
USN group	27.4	1.7	3.2	4.8	5.8	6.0	6.0
Non-USN group	36.0	6.0	6.0	6.0	6.0	6.0	6.0
Control group	36.0	6.0	6.0	6.0	6.0	6.0	6.0

L: left, R: right, USN: unilateral spatial neglect. The maximum score for each area is 6 and the maximum total score is 36.

Table 3. Cervical rotation angle

	To the left		To the right	
	Average	Maximum	Average	Maximum
USN group	4.0	11.0	3.8	9.4
Control group	3.3	11.7	3.4	10.9

USN: unilateral spatial neglect