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RESEARCH ARTICLE

Reaction time analysis in patients with mild left unilateral spatial neglect employing the modified Posner task: vertical and horizontal dimensions

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Abstract
Unilateral spatial neglect (USN) is a common neurological syndrome that develops after a right hemisphere lesion. By examining the performance of the modified Posner task added to the vertical dimensions of the left and right visual fields, we studied whether the lower left area had different neglect symptoms than the other locations. 41 patients with right hemisphere damage were classified into those with mild USN (USN+; $n=20$) and without USN (USN−; $n=21$). Twenty older participants made up the healthy control (HC; $n=20$) group. All participants recorded deficits in the paper-and-pencil tests established for neglect and reaction times in the modified Posner task. In the paper-and-pencil tests, there was no difference in deficit between the upper and lower left visual fields in any of the groups. According to the modified Posner task, the USN+ group exhibited delays in reaction time in the lower left visual field rather than the upper left visual field. Importantly, reaction times were delayed, and USN symptoms persisted, particularly for the lower left quadrant. Our findings imply that the modified Posner task can accurately uncover neglect symptoms in the case of mild USN.

Keywords Hemispatial neglects · Reaction time · Cohort study · Vertical dimensions · Visual field

Introduction

Unilateral spatial neglect (USN) is defined as the lack of contralesional space perception, which often occurs after right- and left-hemisphere damage (Heilman and Valenstein 1979). The left USN (43%) was more frequent than the right USN (19%) (Corbetta et al. 2005; Kleinman et al. 2007, respectively). Studies of USN often focuses on horizontal spatial dimensions (left–right). However, USN can also occur in vertical spatial dimensions (upper–lower). For instance, there are several examples in the literature, not described by the authors, of patients who show neglect in the lower half quadrant of space (Hecaen and Albert 1978; Joanette and Brouchon 1984; Heilman et al. 1985; Halligan and Marshall 1989). Both the vertical neglect of the lower and upper space were first reported by Rapcsak et al. (1998) and Shelton et al. (1990), respectively. Additionally, Mark and Heilman (1997) proposed that some USN patients have both left and lower space neglect. In comparison to patients without USN, those with USN have more limitations in daily activities (Paolucci et al. 2001). Glazer et al. (2017) reported that vertical USN for lower targets could complicate the ability of patients to move in their environment because it prevents the detection of objects or furniture on their way.

Paper-and-pencil tests have previously been used to assess the presence of USN symptoms. However, these tests might provide insufficient evidence for sensitivity. Lindell et al. (2007) reported that patients with stroke showed neglect approximately 17 days poststroke, and detection rates for the paper-and-pencil test representational drawing and line bisection were 6% and 38%, respectively. Paper-and-pencil tests may be poor at detecting USN, especially after

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recovery. Recently, poststroke patients were found to have delayed reaction time in the left visual field. Rengachary et al. (2009) investigated reaction times in neglected space by the Posner task. The Posner task is a reaction time test, in which the targets randomly appear on the screen after spatial cues and you must react as rapidly as possible to the shown targets. Their study found that in patients with chronic USN after stroke, paper-and-pencil scores improve with time; however, the reaction time deficit persists. However, the reaction time task is often restricted to the left–right visual field (Schendel and Robertson 2002; Deouell et al. 2005; Rengachary et al. 2009; Bonato et al. 2010). Few reports have investigated the USN reaction time, including the vertical dimensions on both left and right visual fields. Ladavas et al. (1994) investigated reaction times in a modified Posner task involving the vertical dimensions of the left and right visual fields in severe USN patients with a loss of 60% or more in the left visual field of the line cancelation test. In this study, patients with USN were found to have slow reaction times and poor accuracy rates, especially in the left and lower regions. However, their study focuses on individuals with severe USN. Conversely, the hidden left and lower neglect symptoms in mild USN may only be revealed by reaction time tasks. To date, no study has assessed the performance of a reaction times neglect test in the left and lower visual fields in patients with mild USN after stroke. We hypothesized that lower left neglect persists.

The purpose of this study is to investigate the hypothesis that left and lower neglect persists in patients with mild USN using a modified Posner task.

Materials and methods

Participants

The aim of the study was described to the participants, and signed consent was acquired in accordance with the Declaration of Helsinki. The Institutional Review Board of Kansai Electric Power Hospital (approval number: 19088) and Tokyo Metropolitan University both approved this study (approval number: 19094, 20006). The participants in the trial included first-time stroke patients as well as community-dwelling seniors. Magnetic resonance imaging or computed tomography was used for clinical diagnosis of stroke. The time after stroke was determined by the date of participation in research from the stroke onset. From December 2019 to April 2021, we looked at 141 patients with stroke who were admitted to a rehabilitation institution. Patients having a left brain stroke, bilateral lesions, a prior stroke, reduced consciousness, left-handedness, or cognitive impairment were excluded (mini-mental state examination [MMSE] score ≤ 23). Patients who withdrew their consent

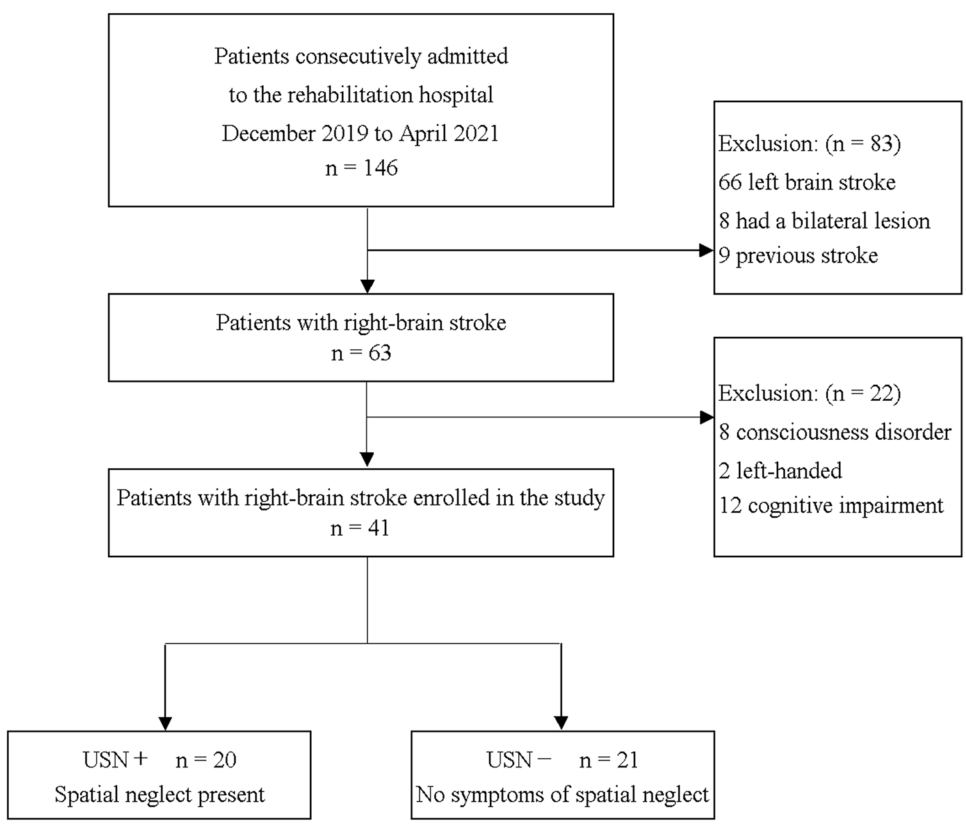


Fig. 1 Patient selection flowchart. USN = unilateral spatial neglect

were also excluded. In this study, 41 people with lesions in the right hemisphere were included (Fig. 1).

The Behavioral Inattention Test conventional subtest (BIT-c) (Wilson et al. 1987) and the Catherine Bergego Scale (CBS) as a behavioral observation scale were used to assess all patients with right hemisphere damages (Azouvi et al. 2003). The BIT-c total score is 146 points, with a score ≤ 131 indicative of USN. The CBS was based on direct observations of a patient's function in 10 real-life situations/tasks. For each of the 10 categories in CBS, there is a score between 0 (no neglect) and 3 (severe neglect); the maximum total score is 30 points, with a score ≥ 1 indicative of USN. Based on their BIT-c and CBS scores, we categorized the patients into the group with USN (USN+ group, $N = 20$) and the group without USN (USN− group, $N = 21$). The healthy control (HC) group (healthy older adults without neurological disorders, $N = 20$) comprised volunteer participants who agreed and understood the goals and overall protocol of this study.

The characteristics of patients are shown in Table 1. There were no significant differences between the three groups with respect to age, F (2.60) = 1.17, $p = 0.32$, sex ($\chi^2 = 1.28$, $p = 0.53$), and between USN+ and USN− with respect to stroke type ($\chi^2 = 0.20$, $p = 0.65$), and time since lesion, ($Z = -0.61$, $p = 0.54$). In the MMSE, there were significant differences between the three groups ($\chi^2 = 17.17$, $p < 0.01$), and in the post-test, there were significant differences between USN+ and USN− ($p < 0.01$), and between USN+ and HC ($p = 0.52$). In the BIT-c and CBS, patients in the USN+ group had mild USN (BIT-c score 101–130 or CBS score ≥ 1).

Procedure

All groups completed a 20–30-min test session in a quiet room and were evaluated in a single day. Outcomes were measured using Bells test (Gauthier et al. 1989), Apples test (Bickerton et al. 2011), and the modified Posner task (Osaki et al. 2021).

Evaluations

1. Bells test: The Bells test consists of 315 stimuli distributed on an A4 sized sheet. The paper is placed in front of the patient who is required to circle with a pencil all 35 bells scattered among 280 distractors. Patients are instructed to complete the test within 5 minutes.
2. Apples test: The Apple test consisted of 150 apples scattered on A4 pages. Two-thirds of the apples were distractor items (half with an opening on the left and half with an opening on the right), and the remaining were targets (full apples). Each participant was asked to cancel only all full apples.
3. Modified Posner tasks: The Posner task is a neuropsychological test used to assess changes in attention (Posner 1980). One of the experimental paradigms is the endogenous cueing task. The cue for the endogenous cueing task is represented by an arrow in the center, pointing to either the left or right. Then, one target is displayed. This task was changed as a modified Posner task with four target presentation positions to evaluate the USN patient's vertical dimensions on the left and right visual fields (Fig. 2).

Using the ASUS ROG STRIX GL703VM computer (ASUS, Taipei, Taiwan), the stimulus was generated and displayed on a 17.3-inch monitor (refresh rate 120 Hz). A numeric keypad (ELECOM TK-TCM011, Osaka, Japan) interfaced with the computer was used to acquire behavioral responses. The software Cedrus Corporation SuperLab 5.0 (San Pedro, USA) was used to create the modified Posner task. Patients were seated approximately 50 cm away from the monitor. A central fixed cross (the fixation point) and four square frames oriented to the right and left sides alongside the horizontal meridian were displayed on the monitor. Each square had a diameter within a 1° viewing angle and a circular target at the center. Each target's diameter subtended a 0.3° visual angle. Within the four peripheral squares, the central targets were placed at a distance with a 4.3° visual angle from the fixation point.

An arrow cue pointing to either the right or left was displayed for 2000 ms. One of 6 randomly assigned stimulus-onset asynchronies (SOAs) then followed the onset of the cue (1000, 1167, 1334, 1500, 1668, 1835, or 2,000 ms). After the variable SOAs, the target (circle) was presented for 3000 ms or until the participant responded in one of the four frames (upper left, lower left, upper right, or lower right). Each session consisted of 120 trials, 80% (96 trials) performed under valid conditions where the clues arrow and target direction are the same and 20% (24 trials) under invalid conditions where the directions are different. We randomly combined valid and invalid trials. Before the experiment, participants were informed that the cue would be informative in predicting the following target location. In addition, during the task, participants were instructed to keep their eyes on a fixation point and respond by pressing a key with the index finger of their right hand as soon as the target appeared. The detection rate and key press timing were recorded. The modified Posner task was a total of 15 minutes, including the practice block.

Table 1 Descriptive variables of study groups

Participant	Age (years)	Sex (M:F)	Type of stroke (I:H)	Time after stroke (days)	MMSE	BIT-c	CBS	Stroke location
USN+ ($n=20$), BIT-c 101–130 or CBS ≥ 1								
1	52	F	I	54	29	128	11	P,O
2	75	F	I	19	24	134	6	P
3	69	M	I	103	26	108	12	F,P
4	68	M	H	31	29	130	8	P,T,BG,IC
5	65	M	H	37	26	106	8	Th,BG,Ins
6	82	F	I	121	27	121	6	P,T,BG,CR
7	76	F	H	123	25	108	17	P,T,Th,BG,CR
8	75	F	H	49	24	102	12	P,T,O,Th,CR
9	79	M	I	76	25	108	10	F
10	50	F	H	84	24	103	18	P,T,Th,BG,IC
11	77	F	I	98	26	126	10	P,O
12	53	M	H	32	26	125	13	P,T,O
13	80	F	H	81	24	129	5	P,Th,BG,CR
14	88	F	I	70	24	137	4	P,BG,CR
15	80	F	I	139	27	136	2	BG,CR
16	76	F	I	42	28	131	9	F,P,T,IC
17	84	F	I	52	24	127	9	P
18	58	M	H	53	30	138	1	Th,CR
19	59	M	I	128	27	133	7	Th
20	42	M	H	59	25	132	4	P,BG,IC,CR
USN– ($n=21$), BIT-c > 131 and CBS = 0								
21	39	M	H	96	29	143	0	Th,BG
22	46	F	H	26	30	144	0	BG,CR
23	59	M	H	23	30	141	0	BG,CR
24	58	F	H	13	30	144	0	P,T,BG
25	49	F	I	83	26	145	0	CR
26	58	M	I	22	30	142	0	BG,CR
27	69	M	I	48	29	139	0	CR
28	53	M	I	124	30	141	0	CR
29	83	F	I	47	25	132	0	IC
30	71	M	I	81	30	145	0	IC
31	77	M	I	87	28	145	0	F
32	84	M	I	106	28	145	0	IC
33	87	M	I	51	28	143	0	F
34	61	M	H	108	29	141	0	BG,Th,IC
35	76	F	I	133	29	139	0	P
36	88	F	I	120	25	142	0	P,T
37	71	M	I	87	29	146	0	IC
38	71	F	H	68	26	134	0	BG,CR
39	80	F	H	82	24	136	0	F
40	74	M	I	32	30	138	0	IC,CR
41	76	F	H	61	29	145	0	CR
Mean ± SD Ratio (:)								
USN+	69 ± 13	8:12	11:9	65 (50–97)[a]	26 (24–27)[a]	123 ± 12	9 (6–11)[a]	
USN–	70 ± 12	12:9	13:8	68 (32–87)[a]	29 (28–30)[a]	141 ± 4	0 (0–0)[a]	
HC ($n=20$)	73 ± 10	9:11	N/A	N/A	29 (28–30)[a]	N/A	N/A	N/A

USN+ participants with post-stroke USN, *USN–* participants without post-stroke USN, *HC* healthy controls, *N/A* not applicable, *F* frontal lobe, *P* parietal lobe, *T* temporal lobe, *O* occipital lobe, *Ins* insula, *Th* thalamus, *BG* basal ganglia, *IC* internal capsula, *CR* corona radiate, *CB* cerebellum, *MMSE* Mini-Mental State Examination, *BIT-c* Behavioral Inattention Test-conventional subtest, *CBS* Catherine Bergego Scale

[a]Median(IQR) instead of Mean

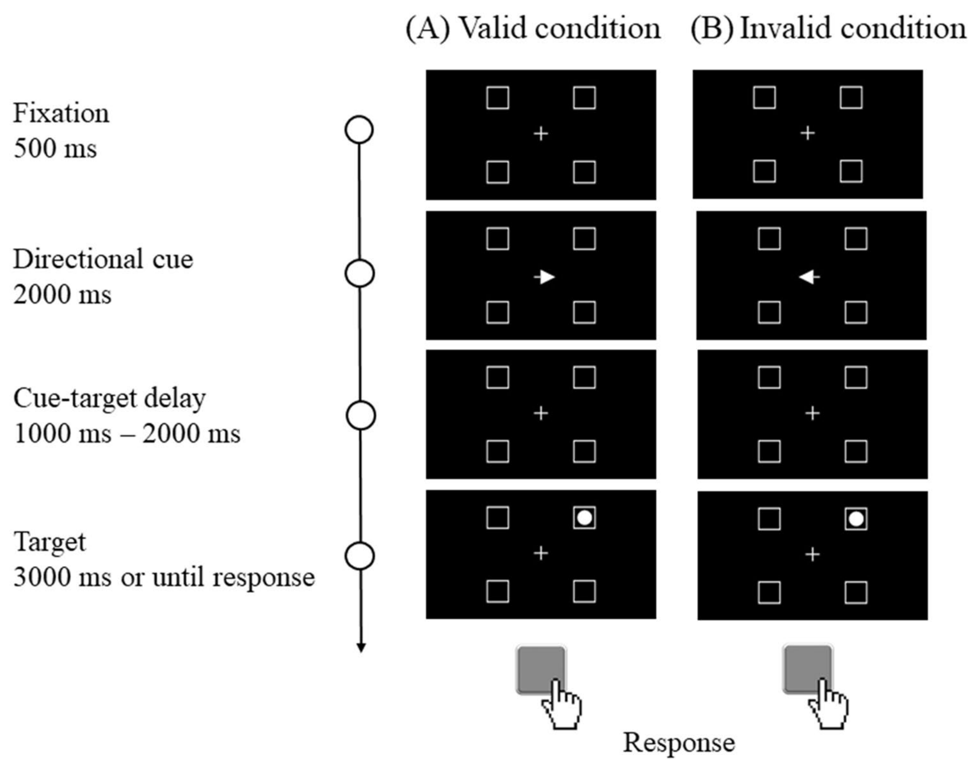


Fig. 2 Modified Posner task screen used in the present experiment. **A** Valid trial, **B** Invalid trial

Table 2 Analyze conditions for modified Posner tasks

Target	Cue	Validity
Upper left	Left	Valid
Lower left	Left	Valid
Upper right	Right	Valid
Lower right	Right	Valid
Upper left	Right	Invalid
Lower left	Right	Invalid
Upper right	Left	Invalid
Lower right	Left	Invalid

Statistical analysis

Sample size

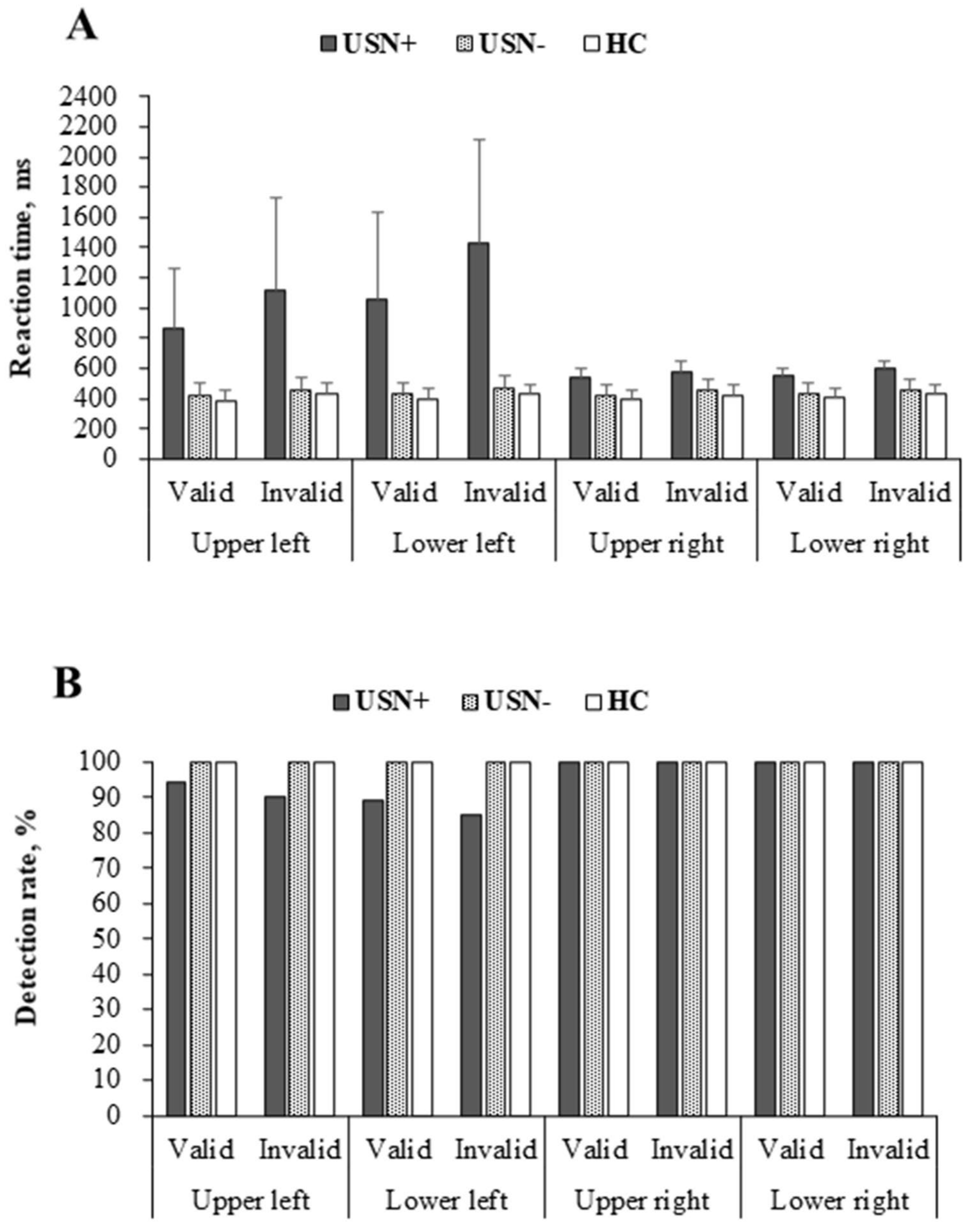
The sample size was calculated using G * power 3.1 (Faul et al. 2009) for the test family (*F*-tests) and ANOVA (repeated measures; within–between interactions). Based on an a priori power analysis conducted with G*Power, assuming a medium effect size ($f=0.25$) as the effect size according to Cohen's *d* (Cohen 1998), a significance level of 5% ($\alpha=0.05$), a statistical power (1-β) of 80%, a 3 group (between) × 4 position (within) interaction, correlation among repeated measures of 0.50, and a nonsphericity correct of 1.00. The sample size indicated 10 participants per group (in total 30 participants). This number has been increased to 10 participants per group to allow for an unexpected dropout. In this study, we have decided on 20 participants per group.

Data analysis

Modified Posner task analyzed the mean reaction time and detection rate for eight conditions (Table 2). The Bells test analysis was divided into three columns on the left, one in the center, and three on the right. The middle column was excluded. Each column contained five targets each. The columns were further divided into upper and lower halves, excluding the middle target, and analysis was included as six targets (Supplementary file 1). The Apples test analysis was divided into two columns on the left, one in the center, and two on the right. The middle column was excluded. Each column contained 10 targets each. The columns were further divided into upper and lower halves, and the analysis included 10 targets.

All statistical analyses were performed with SPSS version 20 (IBM, Tokyo, Japan). The normal distributions of all data were tested by the Shapiro–Wilk test. The modified Posner task data are reported as the mean ± standard error of the mean (Fig. 3). The error bars in Fig. 3 show the standard error of the mean. Modified Posner task performances were analyzed with three-way mixed ANOVAs, wherein groups USN+, USN−, HC were used as a between-subjects factor and target position (upper left, lower left, upper right, lower right) and cue validity (invalid and valid) were used as within-subject factors. Some

Fig. 3 Modified Posner task performance. **A** Reaction time and **B** accuracy are depicted separately for the three study groups, the location where the target appeared, preceding cue (valid or invalid)



comparisons violated the sphericity requirement. Therefore, the F values were reported using the Greenhouse–Geisser correction, and the uncorrected degrees of freedom were reported to show the factor analysis design. To analyze the performance of the Bells and Apples test, we performed the Kruskal–Wallis test in groups as a between-subjects factor and the Friedman test for the number of deficits as the within-subject factors. A post hoc test with Bonferroni correction was used in multiple comparisons between groups ($p = 0.05/3 = 0.017$) and within each group ($p = 0.05/4 = 0.012$). In the USN+ group, correlations between the reaction time in the four positions of modified Posner task were analyzed using the Pearson's correlation (exact significance, two tailed). The level of significance was set at $p < 0.05$.

Results

Paper-and-pencil test

The median results of deficits compared in three groups for different paper-and-pencil tests are shown in Table 3. The Kruskal–Wallis test performed for different parameters of the Bells and Apples test between groups consistently showed significant differences (p always < 0.0001). The Friedman test performed on deficits in the Bells and Apples test as within-subject factors showed no significant difference (p always > 0.09). Post hoc analyses yielded the following differences:

Table 3 Paper-and-pencil test performance

Variable	USN+	USN–	HC
Bells test (omission)			
Total	8 (6–9)	2 (0–2)	1 (0–1)
Upper left	2 (2–3)	0 (0–1)	0 (0–0)
Lower left	2 (1–3)	0 (0–0)	0 (0–0)
Upper right	2 (1–2)	0 (0–1)	0 (0–1)
Lower right	2 (1–2)	0 (0–1)	0 (0–0)
Apples test (omission)			
Total	5 (3–7)	1 (0–2)	0 (0–2)
Upper left	1 (1–3)	0 (0–0)	0 (0–0)
Lower left	1 (1–2)	0 (0–0)	0 (0–0)
Upper right	1 (1–2)	0 (0–1)	0 (0–0)
Lower right	1 (1–2)	0 (0–0)	0 (0–1)
Median(IQR)			

USN+ spatial neglect present, *USN–* no symptoms of spatial neglect, *HC* healthy control

Bells test

The USN+ group had more deficits in all positions than the other groups (p always < 0.01). In the USN+ group, there was no difference in deficit between the upper left and lower left ($z = -0.2$, $p = 0.83$), and between lower left and lower right ($z = -0.8$, $p = 0.40$).

The USN− group was compared with the HC group, and there was no difference in deficit at all positions (p always > 0.02). In the USN− group, there was no difference in deficit between the upper left and lower left ($z = 0.0$, $p = 1.00$), and between lower left and lower right ($z = 0.8$, $p = 0.40$). In the HC group, we found no differences in deficit between the upper left and lower left ($z = -1.0$, $p = 0.32$), and between left and lower right ($z = -1.0$, $p = 0.32$).

Apples test

The USN+ group had more deficits in all positions than the other groups (p always < 0.01). In the USN+ group, there were no differences in deficit between the upper left and lower left ($z = -0.3$, $p = 0.78$), and between lower left and lower right ($z = -1.8$, $p = 0.75$).

USN− group was compared with the HC group, and there were no differences in deficit at all positions (p always > 0.30). In the USN− group, there were no differences in deficit between the upper left and lower ($z = -0.82$, $p = 0.42$) and between lower left and lower right ($z = -1.3$, $p = 0.18$). In the HC group, there were no differences in deficit between the upper left and lower ($z = -1.6$, $p = 0.10$), and between lower left and lower right ($z = 1.89$, $p = 0.59$).

Modified Posner tasks

Results are shown for each of the four individual target positions (upper left, lower left, upper right, and lower right), comparing reaction time and accuracy in the three groups (Fig. 3).

Reaction time

There were violations of the sphericality for the 3 group by 4 position interaction on reaction time. Mauchly's sphere test showed that it violated the assumption for the position and position × validity (Position: $W = 0.007$, $p < 0.01$; Position × Validity: $W = 0.055$, $p < 0.01$); thus, the degrees of freedom were corrected using Greenhouse–Geisser's sphericity estimation (Position: $\varepsilon = 0.51$; Position × Validity: $\varepsilon = 0.63$). The ANOVA revealed main effects for Group, $F(2, 58) = 39.4$, $p < 0.01$; Position, $F(1.5, 89.5) = 19.4$, $p < 0.01$; and Validity, $F(1, 58) = 83.7$, $p < 0.01$. Significant interactions were found for Group × Position, $F(6, 174) = 18.4$, $p < 0.01$; Group × Validity, $F(2,58) = 29.1$, $p < 0.01$; and Position × Validity, $F(1.9, 108.7) = 14.0$, $p < 0.05$; and Group × Position × Validity, $F(3.7, 108.7) = 12.4$, $p < 0.05$. Post hoc analyses yielded the following differences:

The USN+ group had slower reaction times at all target positions (upper left, lower left, upper right, lower right) than all other groups (p always < 0.01). Invalid condition slowed the reaction times at all target positions than valid condition (deficit of reorienting). The upper left position was slower than the upper right position for both the valid and invalid conditions (p always < 0.01). The lower left was slower than the lower right position for both the valid and invalid conditions (p always < 0.01). In particular, in the USN+ group, the reaction times in the lower left position were slower than the upper left position for both the valid and invalid conditions (Valid condition: Upper left vs. Lower left: 860 vs. 1051 ms, $p < 0.01$; invalid conditions: Upper left vs. Lower left: 1112 vs. 1431 ms, $p < 0.01$). In addition, there was no difference between the targets in the upper right and lower right (Valid condition: Upper right vs. Lower right: 541 vs. 554 ms, $p = 0.08$; invalid conditions: Upper right vs. Lower right: 581 vs. 594 ms, $p = 0.18$).

Comparing the USN− and HC groups, we found that there was no difference in reaction times at all target positions. In the USN− group, there were no differences in deficit between the upper left and lower left for both the valid and invalid conditions (p always $= 1.00$). Moreover, there was no difference between the lower left and lower right positions for both the valid and invalid conditions (p always $= 1.00$). In the HC group, there were no differences in deficit between the upper left and lower left for both the valid and invalid conditions (p always $= 1.00$). In addition, there was no difference between the lower left and lower right positions for both the valid and invalid conditions (p always = 1.00).

Table 4 in the supplementary file 2 shows the correlations between the reaction time in the four positions of modified Posner task in the USN+ group. The upper left position was significantly correlated with the lower left position and the upper right position with the lower right position (p always < 0.05).

Accuracy

For the parameter accuracy, the ANOVA revealed main effects for Group, $F(2, 58) = 5.9$, $p < 0.01$; Position, $F(3, 174) = 5.0$, $p < 0.01$; and Validity, $F(1, 58) = 6.2$, $p = 0.25$. Significant interactions were found for Group × Position, $F(6, 174) = 5.0$, $p < 0.01$; Group × Validity, $F(2, 58) = 6.1$, $p = 0.27$; and Position × Validity, $F(3, 174) = 2.5$, $p = 0.73$; and Group × Position × Validity, $F(6, 174) = 2.5$, $p = 0.86$. Post hoc analyses yielded the following differences:

The USN+ group was less accurate at the upper left and lower left positions than all other groups ($p < 0.05$). Invalid conditions were less accurate at the upper left and lower left positions than valid conditions ($p < 0.01$). In particular, in the USN+ group, there was no difference in the accuracy between the upper left and lower left position under both valid and invalid (p always > 0.10).

Comparing the USN− group and HC groups, we found that there was no difference in accuracy at all target positions (p always = 1.00). In the USN− group, there were no differences in deficit between the upper left and lower left (valid condition, $p = 1.00$; invalid condition, $p = 1.00$). In the HC group, there were no differences in deficit between the upper left and lower left (valid condition, $p = 1.00$; invalid condition, $p = 1.00$).

Discussion

To the best of our knowledge, this is the first cross-sectional study focusing on the vertical and horizontal dimensions in the reaction time of mild USN. In the modified Posner task, the USN+ group showed delayed reaction times in the lower left compared to the upper left visual field. However, in the other groups, there was no delay in the lower left compared to other positions (Fig. 3A). In the paper-and-pencil tests, no difference in defects in all positions in all groups (Table 3). Importantly, computerized reaction time tasks are more sensitive than paper-and-pencil tests, especially in the detection of lower left visual field deficits in patients with mild USN.

Previous studies have reported that patients with severe USN had more deficits in the lower left than the upper left visual field in the line cancelation test (Mark and Heilman 1998). The USN+ group in our study included patients with mild USN. USN+ group performed the Bell and Apple tests, which are more sensitive than the line cancelation test. These tests showed no differences in all positions. The differences between previous studies and the results of our study are due to a difference in disease severity of the patients. The modified Posner task in our study showed that the USN+ group delayed reaction time in the lower left position. This lower left delay result is consistent with previous studies (Andres et al. 2019). They investigated both the left–right and upper–lower dimensions of USN in chronic patients showing no more impairment in paper-and-pencil tests by using a computerized detection task (dual-task condition). In one USN patient, the dual-task condition exacerbated left neglect, and another USN patient showed no sign of neglect along the horizontal dimension, but omitted half of the lower target. Their study shows that computerized tasks are more sensitive than paper-and-pencil tests in detecting left and lower visual field deficits. Another previous study reported differences in attention between valid and invalid conditions for Posner tasks (Bonato et al. 2009). In the valid condition, attention is focused on the target (voluntary attention), demonstrating that the response is faster than in the invalid condition (Ristic and Kingstone 2006; Bonato et al. 2018). In the invalid condition, the focus of attention must be disengaged from the cued location and moved to the new location (disengagement of attention). Disengagement deficit has been demonstrated to remain in patients without clinical signs of neglect (Losier and Klein 2001; Bartolomeo and Chockron 2002). Our study showed that the USN+ group had delayed reaction time in the lower left position in both valid and invalid conditions. In other words, voluntary attention and disengagement of attention persisted left lower positions in the USN+ group. In addition, the modified Posner task has been reported to require more attention due to time constraints compared with the paper-and-pencil tests (Bonato 2012). For instance, target presentation in the modified Posner task is short and time-constrained, and a deficit in USN patients limits the possibility of finding the target. However, there is no time limit for a deficit on the left side in the paper-and-pen test, so patients can revisit and gaze at the space on the left side. Therefore, modified Posner task was able to find a "covert neglect sign" in the lower left visual field of mild USN patients who could not be detected by the paper-and-pencil tests.

The neurophysiological mechanisms of horizontal and vertical attention have been reported as follows. Regarding attention in the horizontal direction, Corbetta et al. (1993) investigated the activity of the brain region in healthy subjects when attention was directed to the left or right visual field by positron emission tomography. As a result, activation was observed in the right parietal lobe when attending to the left visual field and in bilateral parietal cortices when attending to the right visual field. Moreover, Meister et al.

(2006) observed that single-pulse transcranial magnetic stimulation over the right temporo-parietal junction caused extinction-like performance in a detection task for visual stimuli presented on the left side. Thus, several studies have shown that attention to the left visual field is related to the right parietal lobe. Conversely, attention in the vertical direction is often investigated by the radial line bisection judgments. In the radial line bisections on the desk, the proximal portion of the line visually projects to the upper visual field and the distal portion of the line falls on the lower visual field (Julayanont et al. 2019), suggesting that the upper visual field and far space are primarily mediated by the ventral stream, whereas the lower visual field and near space are predominantly processed by the dorsal stream (Previc 1990). The ventral stream interconnects the striatum and temporal lobe, and enables the visual identification of objects. The dorsal stream interconnects the striatum and parietal lobe, which allows the visual location of objects (Mishkin et al. 1983). Specialization of the ventral and dorsal visual streams is based by functional magnetic resonance imaging (fMRI) study. Chen et al. (2012) investigated brain activity in allocentric/egocentric judgments on objects located in near or far space. The results of this study showed that the ventral stream (temporal lobe connections) was activated in the far space (upper visual field), whereas the dorsal stream (parietal lobe connections) was activated in the near space (lower visual field). In other fMRI studies (Fink et al. 2001), healthy subjects were presented with horizontal and vertical bisection tasks. The results showed that the right parietal lobe was most activated in both orientations. These reports indicate that the right parietal lobe affects the left and lower visual fields. Our results are consistent with the previous studies (Corbetta et al. 1993; Meister et al. 2006; Fink et al. 2001; Chen et al. 2012). In our study, the USN+ group with vertical and horizontal spatial neglect mostly has in the right parietal lobe lesion (Table 1). The lesion in the right parietal lobe caused impairment in the dorsal stream and deficit in attention in the lower left visual field. Therefore, the USN+ group showed delayed reaction time in the combination of left and lower spatial neglect.

The results of this study suggest that the modified Posner task remains a USN symptom in the in the lower left visual fields. Deficits in daily living activities in patients with USN are often observed in the lower left direction. An example could be the collision of the left foot while walking. In this case, we have not investigated such behavioral observations and reaction time during walking. In future studies, it would be necessary to clarify the relationship between the collision site during walking and modified Posner task.

Study limitations

This study has some limitations. First, our study analyzes only mild USN cases, and it is unclear how the reaction time of modified Posner task differs depending on the severity of USN. In addition, this study did not analyze brain lesion mapping. In the future, it is necessary to include the results of lesion mapping divided by USN severity in relation to the modified Posner task. Second, the modified Posner task in this study requires maintaining attention to the task for 10 min, which may be difficult for patients with severe USN. Future research should include the use of eye tracking during the task and the development of tasks that use a dual-task approach to assess upper and lower visual fields in a short time. Third, this study does not consider the association between lower left collisions during walking and the modified Posner Task, so careful judgment should be made as to whether it affects walking. Finally, the paper-and-pencil test and the modified Posner task used in this study differ in the orientation of the participant's head during the task, so the type of test is not the same. For instance, paper-and-pencil tests were usually evaluated at a desk, so that the lower quadrant of the test paper is closer to the body, while the upper quadrant is farther away from the body. In contrast, in the modified Posner task, the upper and lower quadrants were evaluated at the same distance from the body. These different types of tests may have shown the results of our research. In the future, additional studies with the same direction of the head during the paper-and-pencil test and the modified Pozner task are needed.

Conclusions

Our study found that computerized reaction time tasks are more sensitive than paper-and-pencil tests especially in the detection for lower left quadrants deficits in patients with mild USN. Therapists should consider using a modified Posner task if patients with mild USN are asymptomatic on paper-and-pencil test but show symptoms of USN in their daily lives.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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