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Research article

Influence of unilateral spatial neglect on vertical perception in post-stroke pusher behavior

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ABSTRACT

Pusher behavior (PB) impairs verticality in the frontal plane and is often associated with unilateral spatial neglect (USN). However, it is unclear whether USN affects verticality among patients with PB. We aimed to clarify the characteristics of verticality among PB, with and without USN. The study included 43 patients with right hemisphere stroke, including 12 without PB or USN, 10 with only USN, 10 with PB only, and 11 with PB and USN, and 15 age-matched healthy individuals. The subjective visual vertical (SVV), subjective postural vertical with eyes closed (SPV), and subjective postural vertical with eyes open were assessed. Under each condition, the mean (tilt direction) and standard deviation (variability) across trials were calculated. The variability of SVV was significantly greater among patients with only USN (6.9° ± 5.9°) or those with PB and USN (7.6 ± 4.3°). On SPV, the contralesional tilt was significantly greater, with higher variability, in patients with only PB (-2.2° ± 1.1° and 6.3° ± 1.4°, respectively) and those with PB and USN (-2.1° ± 2.0° and 6.6° ± 2.0°, respectively) than in the other groups. In patients with PB, SVV differed depending on the presence of USN, but it was suggested that SPV might not be affected by USN. These findings are important to plan PB treatment.

1. Introduction

Pusher behavior (PB) is a severe lateral balance disorder in which a person actively pushes away from the non-paretic side, resulting in a tilt away from vertical, in the frontal plane [1–3]. This postural tilt is resistant to passive correction [1–3], and patients express a fear of falling toward the non-paretic side [4]. PB increases the length of hospital stay post-stroke [5–8] and is associated with poor functional outcomes on discharge [7,9] and a low rate of discharge to home [9].

PB is known to impair subjective vertical perception in frontal plane, and is thought to arises from an impairment in subjective postural vertical with eyes closed (SPV) [10,11], which aligns the body with perceived earth vertical and reflects the graviceptive perception of the body [12]. PB also increases the variability in SPV (measured as the standard deviation across trials), compared to patients without PB and healthy controls [13].

PB is often presenting with unilateral spatial neglect (USN) [14]. USN is also associated with right hemisphere stroke and is strongly associated with misperception of subjective visual vertical (SVV) in frontal plane, which is the methods to measure visual orientation [15,16], resulting in a contralesional tilt [17–19] and increased variability in SVV [18,19], compared to stroke patients without USN and healthy controls. On the other hand, USN is related to an ipsilesional tilt of SPV in the chronic phase of the stroke [20]. In addition, postural orientation is known to be closely related to USN [21,22].

Given that PB is often associated with USN, it is possible that USN can influence vertical perception in patients with PB. To date, however, research on the vertical perception among patients with PB has not been conducted relative to the presence or absence of USN. Furthermore, there are few reports that measured both SVV and SPV for

Abbreviations: BITC, Behavioral Inattention Test Conventional Subtest; PB, pusher behavior; SCP, scale for contraversive pushing; SPV, subjective postural vertical; SPV-EO, subjective postural vertical-eyes open; SVV, subjective visual vertical; USN, unilateral spatial neglect; VB, vertical board

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PB at an early phase. Therefore, we aimed to compare the direction and variability in SPV and SVV among patients with PB with and without USN.

2. Material and methods

2.1. Study design and statement of ethics

Our prospective cross-sectional study was approved by the Ethics Review Board of our institution and university. All participants provided written or oral informed consent. The study was registered with the University hospital Medical Information Network Clinical Trials Registry (UMIN-CTR number: UMIN000028446).

2.2. Participants

Forty-three patients with right hemisphere stroke were recruited. Patients with acute ischemic/hemorrhage stroke, confirmed by computed tomography or magnetic resonance imaging, were recruited through the inpatient rehabilitation program at our stroke center. Medically stable eligible patients were further screened for the following inclusion criteria: first hemisphere stroke, stable neurological symptoms and cardiorespiratory dynamics, absence of orthostatic hypotension, and ability to understand instructions. Those with altered consciousness, aphasia, history of dementia, a psychiatric disorder, vestibular dysfunction, neurological disorders other than stroke, or orthopaedic conditions that could affect the reliable measurement of subjective vertical perception were excluded. Patients from whom informed consent could not be obtained were also excluded.

The control group included 15 healthy adults, with no history of neurological or musculoskeletal disorders, and vestibular disorder matched, as closely as possible, for age with the patient group.

2.3. Assessment of PB and USN

PB was assessed using the scale for contraversive pushing (SCP) [10], which includes the following: postural asymmetry, abduction or extension of the non-paretic extremities, and resistance to passive postural correction. Each item was scored from 0 to 2 and summed to yield a total score ranging from 0 to 6, with a score of 6 indicating severe PB, and according to the cut-off of Baccini, a score > 0 for each item being indicative of PB [23]. The SCP was assessed by a physical therapist.

USN was assessed using the Behavioral Inattention Test Conventional Subtest (BITC) [24], which includes the following six items: line crossing; letter cancellation; star cancellation; figure and shape copying; line bisection; and representational drawing. The BITC score ranges from 0 to 146 points, with a score ≤ 131 indicative of USN. BITC, measured by an occupational therapist or a speech therapist, was conducted in a quiet room of 7.81 m^2. Participants sat on chairs with a backrest, with their feet on the ground.

2.4. Measurement of SVV

SVV was assessed in a bright room, using a previously described method [25], with participants seated, feet flat on the floor, trunk fixed to the board (using belts) and covered with a non-stretchable cloth, and the head was not fixed, but freely maintained in an upright position (Fig. 1A). Two computers were used for measurements. A visual reference indicator was projected, at eye level, on a computer screen placed 50 cm in front of the participants. The screen was linked via a USB cable to a second screen that was visible to the experimenter. Participants viewed the visual display through a cylindrical tube that obscured the frame of the computer display screen, thus removing clues regarding verticality. To assess SVV, the visual indicator was rotated from a horizontal position, either to the left (A) or right (B), at a rate of 5°/s, and the rotation stopped when the participant reported that the indicator was in a true vertical position. Eight trials were completed, using an ABBABAAB sequence, with the deviation from true verticality recorded for each trial.

2.5. Measurement of SPV and SPV with eyes open (SPV-EO)

SPV and SPV with eyes open (SPV-EO) were measured in a bright room, using a vertical board (VB), with a semicircular rail attached to the bottom [25,26]. Participants sat on the VB, with arms folded across their chest and feet not in contact with the floor, the trunk was fixed to the board (using belts); but no restraint on the head and lower limbs was provided. The VB was rotated from a starting tilt position of 15° or 20°, either to the left (A) or right (B), toward a vertical position, at a rate of ~1.5°/s; the rotational displacement of the VB was manually controlled as steadily and smoothly as possible by two experimenters (Fig. 1B). Participants indicated when they perceived themselves to be in a true vertical position, and the tilt of the VB was recorded using a digital inclinometer. Eight trials were performed in an ABBABAAB or BAABABBA sequence, each for SPV (wearing opaque goggles) and SPV-EO (while looking inside the rehabilitation center).

2.6. Data processing

The true vertical position was considered at 0°, with deviations to the right and left recorded as positive and negative tilt values, respectively. The mean (tilt direction) and the standard deviation (variability) were calculated across the eight trials for each SVV, SPV, and SPV-EO condition. Tilt direction was defined based on the direction and magnitude of vertical perception, whereas variability was the instability of vertical perception.

2.7. Procedure

The SCP and BITC were assessed before measurement of subjective vertical perception, during which, firstly, participants were evaluated for SVV, followed by SPV and SPV-EO. The order of SPV and SPV-EO measurements was random. If they complained of fatigue, there was a sufficient break between each measurement.

2.8. Statistical analysis

Differences in baseline demographic data and parameters of vertical perception between groups were evaluated using one-way analysis of variance (ANOVA), with post-hoc analysis performed using a Bonferroni multiple-comparison test to compare the between-group difference. The relationships between vertical perception and SCP or BITC were analyzed by Pearson's correlation coefficient. All analyses were performed using IBM SPSS Statistics (ver. 25.0, SPSS Inc., Tokyo, Japan), with the level of significance set at 5%.

A post-hoc power calculation was performed to determine the power (1-β) and effect size with significance set at 5% on G*power 3.1 [27]. The effect size was set with reference to Cohen's f, i.e. 0.10 (small effect size), 0.25 (medium effect size), and 0.40 (large effect size) [28].

3. Results

Individual demographic and vertical perception data are shown in Table 1. There was no difference in the age across five groups ($F_{4,53} = 0.491$, $p = 0.742$), and days from stroke onset ($F_{3,39} = 0.428$, $p = 0.734$) across four stroke groups. A significant group on SCP was identified ($F_{3,39} = 84.117$, $p < 0.001$), with the SCP score being higher in the P and PN group than other stroke groups (all, $p < 0.05$). A significant group effect on the BITC score was also identified ($F_{3,39} = 29.899$; $p < 0.001$), with the BITC score being lower in the N and PN group than in other stroke groups (all, $p < 0.05$).

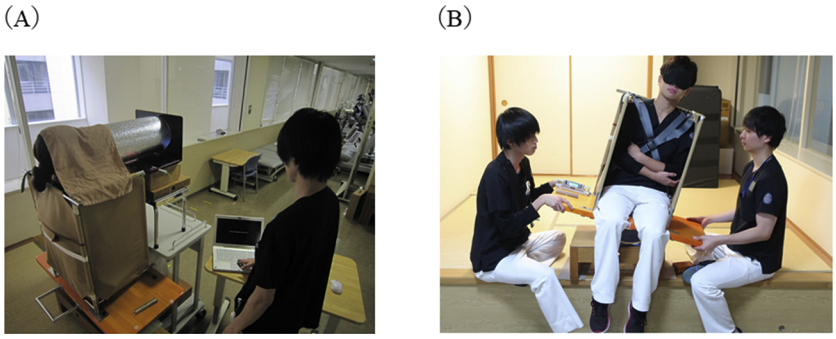

Fig. 1. Measurement of subjective visual vertical and subjective postural vertical (A) Participants seated on vertical board, and viewed the visual display through a cylindrical tube due to measure SVV. (B) This picture shows left side starting position on SPV (participant wore opaque goggles). Two experimenters controlled the vertical seat by tilting it toward a vertical position.

The normative values were calculated based on the healthy subjects' data and defined as mean ± 2 SD. SVV was -0.7° ± 1.8° [range, -4.3° to 2.9° (min to max)]. SPV was -0.2° ± 1.1° (range, -2.4° to 2.0°). SPV-EO was 0.4° ± 0.9° (range, -1.4° to 2.2°). Thus, normative values ranged from -4.5° to 4.5° for SVV and from -2.5° to 2.5° for SPV and SPV-EO.

With regard to SVV, although a significant group main effect was not identified on the mean SVV tilt ($F_{4,53}$ = 1.385, p = 0.252, f = 0.32, 1-β = 0.43; Fig. 2-A), SVV variability did differ between the groups ($F_{4,53}$ = 8.086, p < 0.001, f = 0.78, 1-β = 1.00; Fig. 2-B). Variability was higher in the N and PN group than in the any other groups (all, p < 0.05).

In contrast, a significant main group effect was identified for both the mean SPV tilt ($F_{4,53}$ = 6.943, p < 0.001, f = 0.72, 1-β = 0.99; Fig. 2-C) and variability ($F_{4,53}$ = 12.267, p < 0.001, f = 0.96, 1-β = 1.00; Fig. 2-D). On the post-hoc analysis, the contralesional tilt was greater in the P and PN group than in the any other groups (all, p < 0.05). The variability was significantly higher in the P and PN group than in the any other groups (all, p < 0.05).

Under the SPV-EO condition, however, there was no main group effect on the mean tilt direction ($F_{4,53}$ = 1.295, p = 0.284, f = 0.31, 1-β = 0.40; Fig. 2E), although there was a main group effect on the variability of tilt ($F_{4,53}$ = 14.269, p < 0.001, f = 1.04, 1-β = 1.00; Fig. 2F), with greater variability in the N and P and PN group than in the any other groups. Moreover, PN group demonstrated significantly high variability than P group (p < 0.05).

In all stroke patients, the tilt direction of SPV, and variability of SPV-EO and SPV were significantly correlated with SCP (r = -0.535, p < 0.001; r = 0.433, p = 0.004; r = 0.565, p < 0.001), whereas the tilt direction of SVV and SPV-EO and variability of SVV were not significantly correlated (r = -0.035, p = 0.824; r = 0.041, p = 0.796; r = 0.224, p = 0.148). Moreover, the variability of SVV and SPV-EO was significantly correlated with BITC (r = 0.752, p < 0.001; r = -0.451, p = 0.002), whereas the tilt direction of SVV, SPV-EO, and SPV and variability of SPV were not significantly correlated (r = -0.124, p = 0.427; r = -0.105, p = 0.504; r = 0.044, p = 0.778; r = 0.165, p = 0.290).

4. Discussion

To the best of our knowledge, this is the first study to report on the influence of USN on SPV among patients with PB, and to consider variability in vertical perception, in addition to the direction and magnitude of tilt, as an outcome.

Our findings indicated that the tilt direction of SVV was not significantly different among the five groups in the acute phase after stroke. The findings of Saj et al.'s [17] study, who performed measurement in a darkroom with the subjects orientated vertically, while rotating a luminous rod, are noteworthy. The subject's head and trunk were fixed to a sitting device for measurement. They do not agree with the general consensus on the absence of SVV deficit for acute stroke, reporting an SVV bias toward the paretic side in patients with USN only but a bias toward the non-paretic side among patients with USN and PB. However, SVV in this study was measured using a novel task in which participants manipulated visual indicators by hand, bringing motor elements into play in addition to the visual input. As such, findings from this study cannot be meaningfully compared to our results, which are based on visual input alone. Our results are supported by the findings of Karnath et al. [10] and Johannsen et al. [29]. Karnath et al. [10] measured the task of presenting a glowing rod on a computer screen in a completely dark room while localizing the orienting rod vertically. SVV measurements were performed in a wheelchair with the head and trunk not fixed. They reported nearly perfect SVV among adult patients who had sustained a recent unilateral brain damage and who presented with USN or USN and PB. Similarly, Johannsen et al. [29] did not identify a difference in SVV tilt in the acute phase of stroke recovery among patients with PB, compared to a control group. In a subgroup analysis comparing patients with PB and USN to patients with PB only (the PN and P groups, respectively, in our nomenclature), Johannsen et al. [29] identified an SVV tilt toward the paretic side in both subgroups, but without between-group difference. Pérennou et al. [11] used a measurement device similar to that of Karnath et al. [10] and Johannsen et al. [29], but with different a study setting. The subject's head and trunk were fixed to a sitting device. They showed that patients with PB demonstrated contralesional tilt, and discussed that subjective vertical perceptions are influenced by measuring days of stroke onset. These findings indicate that neither USN nor PB causes deficits in visual orientation per se in the early phase of stroke recovery, although the long-term effects of USN and PB on SVV in the chronic stage of recovery remain an issue of controversy, with some studies reporting an SVV bias toward the paretic side.

We identified higher SVV variability in the N and PN groups and SVV variability is strongly related to the BITC score. Bonan et al. [30,31] found that SVV variability was particularly high among patients with right hemisphere stroke involving the temporo-parietal junction, which are areas of the cortex involved in the processing of visual information, with impairment in this processing resulting in spatial deficits. Similarly, Karkhoff et al. [18,19] reported a significant SVV bias toward the paretic side among patients with USN, with higher variability in SVV compared to healthy control group. These findings imply that USN could induce instability in the vision-based judgment of verticality, in agreement with our findings. However, we underscore our finding that SVV variability was not different in the P group than in the control and non-PN groups, indicating that the deficits in vertical perception with PB are mediated by the USN.

On the SPV, patients with PB (PN and P groups) demonstrated a significantly greater contralesional tilt and higher variability than patients in other groups, with magnitude and variability not influenced by the presence or absence of USN. In fact, no difference in SPV was noted between the USN only group (N) and the non-PN and control groups. Therefore, PB has a negative impact on somatic graviception, whereas spatial neglect does not appear to have an impact on graviceptive perception. The result that USN does not affect SPV is supported by Karnath et al. [10]. They argued that there were obstacles in the recognition of gravity perception specific to PB cases that did not depend

Table 1
Individual demographic data of the 43 patients with right hemisphere stroke and 15 elderly subjects.

No.	Age	Sex (M/F)	Etiology (I/H)	Lesion site	Hemiparesis (Yes/No)	SCP	BITC	Days from onset	SVV		SPV-EO		SPV	
									Tilt direction	Variability	Tilt direction	Variability	Tilt direction	Variability
non-PN group (n = 12)														
1	74	M	I	CS, CR, ICa	Yes	0	144	15	2.8	1.4	0.5	3.7	−1.8	4.5
2	46	F	H	ICa, Th	Yes	0	142	16	−3.0	1.9	−2.2	2.2	−0.9	4.9
3	73	F	I	CR, S	Yes	0	145	28	−4.1	1.1	1.8	1.8	−0.5	3.8
4	64	F	H	T, IC, ICa, S	Yes	0.5	141	10	−2.7	1.4	−3.6	3.0	0.7	3.2
5	66	M	I	CR, S	Yes	0	139	15	−1.4	1.0	−1.7	1.5	0.1	2.0
6	70	F	I	CR, S	Yes	0.5	146	20	0.3	0.7	0.0	3.3	−0.3	3.0
7	66	M	I	CR, ICa	Yes	0	144	14	−0.4	0.8	−0.3	3.8	0.9	4.4
8	55	M	I	CR, S	Yes	0	140	15	−1.6	1.7	3.0	1.9	0.9	3.7
9	72	M	I	P, T, IC, CR	Yes	0	143	8	3.1	0.9	−0.1	4.0	0.2	4.4
10	86	F	I	CR, S	Yes	0	146	15	0.1	1.8	0.4	2.0	−0.6	2.1
11	54	M	I	CR, S	Yes	0	140	12	−1.0	1.3	−1.7	1.3	−1.0	2.7
12	59	F	I	Fl, P, IC, CS, CR	Yes	0	145	14	1.1	2.9	−2.0	3.7	−2.2	2.8
	65.4 (10.8)	6 (50.0)/6(50.0)	10 (83.3)/2 (16.7)		12 (100.0)/0 (0.0)	0.1 (0.2)	142.8 (2.4)	15.2 (5.0)	−0.6 (2.2)	1.4 (0.6)	−0.5 (1.8)	2.7 (1.0)	−0.4 (1.0)	3.5 (1.0)
N group (n = 10)														
13	79	F	H	P, T, O	No	0	48	14	5.1	23.0	−0.9	2.9	−0.5	1.3
14	61	M	I	Fl, P, T, CR, S,	Yes	1	124	11	−6.8	3.7	−0.2	6.6	0.3	4.0
15	68	M	H	T, IC, CR, S	Yes	0.25	111	12	−2.8	4.1	−0.4	7.5	−2.2	3.4
16	77	M	I	Fl, P, O, CR	No	0	58	3	−0.6	10.2	−0.9	5.8	−0.1	2.1
17	76	F	H	P, T	No	0	91	9	−0.7	5.2	−1.4	3.6	−1.2	4.6
18	46	F	I	Fl, P, T, CR	Yes	0	95	12	−6.2	4.2	1.2	5.3	0.0	7.8
19	40	F	H	Fl, T, IC, CR, S, Th,	Yes	0.25	95	28	−5.4	3.3	−0.9	4.9	−1.4	3.4
20	60	M	I	Fl, P, CR, ICa, S	Yes	0	88	16	1.7	5.1	0.2	4.9	0.1	3.1
21	65	M	I	P, T, CS, CR, S	No	0	104	15	−4.2	4.0	0.1	8.7	0.5	5.2
22	67	F	I	P, T, CR	Yes	0	64	20	−2.8	6.0	1.1	10.1	3.0	5.3
	63.9 (12.9)	5 (50.0)/5 (50.0)	6 (60.0)/4(40.0)		6 (60.0)/4 (40.0)	0.2 (0.3)	87.8 (24.1)	14.0 (6.6)	−2.3 (3.7)	6.9 (5.9)	−0.2 (0.9)	6.0 (2.2)	−0.2 (1.4)	4.0 (1.8)
P group (n = 10)														
23	75	M	H	ICa, CR, Th	Yes	3.25	142	8	0.9	0.8	−1.9	4.7	−2.5	5.0
24	86	F	I	Fl	Yes	3.75	135	13	−0.7	2.3	−0.4	5.2	−2.3	4.8
25	71	F	I	P, ICa, Th	Yes	3	146	8	14.4	2.6	−0.7	7.2	−3.0	5.3
26	53	M	I	Fl, P, T, IC, CR, S	Yes	3.75	138	12	−4.6	2.1	0.3	6.5	−1.0	9.2
27	74	M	H	ICa, CR, Th	Yes	2.75	143	7	4.9	1.7	−0.8	3.1	−3.0	6.6
28	58	M	H	IC, ICa, CR, S	Yes	3.25	141	14	0.0	2.6	−0.1	5.4	−1.2	6.5
29	68	F	H	ICa, CR, Th	Yes	2.5	133	12	6.9	2.2	−1.1	7.7	−2.6	7.7
30	69	M	I	ICa, CR	Yes	3.5	136	9	−2.6	1.6	0.5	3.9	−1.8	5.4
31	42	F	I	Fl, P, T, CS, CR, S	Yes	2	136	23	−2.9	2.1	−1.1	5.1	−4.4	6.6
32	67	F	H	ICa, CR, S	Yes	2.75	136	15	−0.8	1.5	−1.7	3.8	−0.7	5.4
	66.3 (12.4)	5 (50.0)/5 (50.0)	5 (50.0)/5 (50.0)		10 (100.0)/0 (0.0)	3.1 (0.5)	138.9 (4.0)	12.1 (4.7)	1.5 (5.7)	1.9 (0.5)	−0.7 (0.8)	5.3 (1.5)	−2.2 (1.1)	6.3 (1.4)
PN group (n = 11)														
33	71	M	I	Fl, P, ICa, CR, S,	Yes	3.75	119	8	1.4	2.9	0.1	4.3	−6.1	5.3
34	53	F	H	IC, ICa, CR, S, Th,	Yes	2.5	65	15	−2.1	2.9	−1.3	9.5	−1.4	6.7
35	70	M	H	T, IC, ICa, CR, S,	Yes	2.5	60	12	−2.7	8.4	1.4	11.9	0.2	10.1
36	72	F	I	Fl, P, ICa, CR, S	Yes	3.25	23	8	7.3	20.5	−0.7	7.0	0.1	9.1
37	72	F	H	ICa, CR, Th	Yes	4.5	54	5	−6.3	6.5	1.5	6.0	−1.2	4.6
38	83	F	I	Fl, P, T, CS, CR	Yes	3.25	112	11	2.6	1.4	0.3	8.4	−0.7	6.6
39	50	F	H	T, IC, ICa, CR, S,	Yes	2.75	93	20	−3.9	1.6	0.9	5.2	−0.7	6.6
40	78	M	H	ICa, CR, S, Th,	Yes	5.5	99	6	−10.5	16.7	0.0	13.0	−1.4	8.8
41	76	M	I	Fl, P, T, IC, CS, CR, S	Yes	3	79	30	4.4	6.3	−1.4	5.0	−3.5	6.7
42	80	F	H	IC, ICa, CR, S,	Yes	6	3	27	−5.5	12.0	−1.3	5.1	−3.4	4.2
43	66	M	I	Fl, P, T, IC, CS, CR, S	Yes	3.5	82	12	−0.4	4.2	0.7	7.7	−4.3	4.3
	70.1 (10.4)	5 (45.5)/6 (54.5)	5 (45.5)/ 6 (54.5)		11 (100.0)/0 (0.0)	3.7 (1.1)	71.7 (34.1)	14.0 (8.3)	−1.4 (5.1)	7.6 (6.3)	−0.3 (1.1)	7.6 (2.9)	−2.1 (2.0)	6.6 (2.0)
Control group (n = 15)														

(*continued on next page*)

Table 1 (*continued*)

No.	Age	Sex (M/F)	Etiology (I/H)	Lesion site	Hemiparesis (Yes/No)	SCP	BITC	Days from onset	SVV		SPV-EO		SPV	
									Tilt direction	Variability	Tilt direction	Variability	Tilt direction	Variability
1	60	M							−3.8	0.9	2.1	1.5	0.7	2.3
2	74	F							−3.4	0.7	−0.1	4.3	−1.3	3.5
3	67	M							−0.6	2.2	−0.5	3.4	0.5	2.6
4	70	M							1.0	0.9	1.7	2.9	1.5	5.7
5	68	M							−0.5	0.8	−0.4	3.0	0.0	2.2
6	68	F							−2.7	1.3	0.1	3.8	−0.6	5.9
7	69	F							−0.6	2.1	1.2	2.5	0.5	3.2
8	60	M							−1.1	1.1	1.5	3.1	0.3	2.6
9	80	F							1.6	1.1	−0.3	2.5	−1.9	5.2
10	59	F							1.0	1.4	0.1	3.2	0.8	2.9
11	47	M							−2.5	2.0	0.1	3.4	−0.6	2.5
12	71	F							2.0	0.8	0.1	2.5	−1.8	2.6
13	74	M							−0.5	0.7	0.7	2.2	1.0	3.1
14	66	M							−1.4	1.9	−0.1	4.1	−0.4	4.2
15	72	M							1.4	0.7	−0.9	1.9	−1.8	0.8
	67.0 (8.0)	9 (60.0)/ 6 (40.0)							−0.7 (1.8)	1.3 (0.6)	0.4 (0.9)	3.0 (0.8)	−0.2 (1.1)	3.3 (1.4)

F, female; M, male; I, infarction; H, hemorrhage; Fl, frontal lobe; P, parietal lobe; T, temporal lobe; O, occipital lobe; IC, insular cortex; CS, central sulcus; CR, corona radiata; ICa, internal capsule; S, striatum; Th, thalamus; SCP, scale for contraversive pushing; BITC, behavioral inattention test conventional subtest; SVV, subjective visual vertical; SPV-EO, subjective postural vertical-eyes open; SPV, subjective postural vertical; C, control; non-PN, patients without pusher behavior (PB) and unilateral spatial neglect (USN); N, patients with only USN; P, patients with only PB; PN, patients with PB and USN.
*Continuous data are presented as mean (standard deviation), and categorical data are presented as n (%).

on the USN. In addition, the variability of the SPV was not affected by USN in our results; hence, it is considered to be an obstacle specific to PB. Bergmann et al. [13] reported significantly greater SPV variability in both the frontal and sagittal planes during standing among patients with PB, compared with those without PB, indicative of a lower sensitivity to somatosensory graviception among patients with PB. This reduced gravitational sensitivity could explain, in part, the higher SPV variability that we observed among patients with PB. Of note was the absence of any difference in SPV-EO among our five groups, which corroborates the findings of Karnath et al. [10] who reported an absence of a significant difference in the SPV-EO tilt direction between patients with USN and those with USN and PB. However, we did observe a significantly higher SPV-EO variability in our N, P, and PN groups, with this variability being specifically higher in the PN group than in the P group and significantly associated with the SCP and BIT in all stroke patients.

Karnath et al. [10] analyzed the difference of SPV and SPV-EO (with visual environment) in patients with and without PB and showed that SPV-EO in the pusher group was not significantly different between groups, while SPV was significant with ipsilesional tilt in the pusher group compared with non-pusher group. They discussed that PB may occur from cognitive gap. However, our values, both in terms of direction and magnitude, are quite different from the value of approximately 18° reported by Karnath et al. [10]. We measured an SPV tilt of -2.2° among patients in the P group and -2.1° among patients in the PN group. This discrepancy might be due to differences in the severity of PB between the study samples, with SCP scores of 5.5–6 among patients with PB in Karnath et al.'s study [10], compared to an average SCP score of 3 in our study, indicative of milder PB. However, patient 40 and patient 42 had severe PB, scoring 5.5 and 6.0 points, respectively. Both patients showed a contralesional tilt of SPV. Moreover, the maximum starting angle in Karnath et al.'s study [10] was 35°, compared to 20° in our study. However, neither the difference in the starting angle between these two studies nor the fact that we manually moved the WB in our study can explain the difference in the direction of tilt, contralesional in our study and ipsilesional in Karnath et al.'s study [10]. On another point, the measurement method may have influenced the magnitude of the SPV value. Saj et al. [32] reported that the value of vertical perception decreased when the plantar was not grounded compared with the plantar grounding during sitting position. In addition, as reported by Punt and Riddoch [33], it may be possible to influence the vertical perception by adding physical somatosensory information such as belt fixation.

Regardless of the presence or absence of USN, the SPV of the PB patients showed contralesional deviation and unstable. Since the variability of SPV-EO is also high, it is thought that the vertical representation of the body for PB patients is ambiguous regardless of whether the eyes open or closed. Furthermore, the variability of SPV-EO and SVV was higher in the PB with USN than in the PB without USN. Therefore, in the PB with USN, it seems that visual and somatosensory modalities are complexly impaired. In other words, since the ability to adjust one's body with respect to external reference may be reduced, the use of visual feedback should be judged carefully. Furthermore, it was reported that the variability of SVV affects the balance function in stroke patients, so the ambiguity of these visual judgments may affect the recovery of the balance function and of the PB itself in PB patients. In the future, it will be necessary to investigate the relationship between the recovery process of the PB or of the balance function and SVV in PB patients.

The main limitation of this study was that there were few cases that deviated from the normal range on the tilt direction of SPV for the PB patients. Conventionally, PB is caused by abnormal SPV [10,11]. However, considering that there are few examples that deviated from the tilt direction in our study, the PB may not have been caused by an abnormal vertical recognition alone. In the previous study [20], since there was no abnormality of the tilt direction of SPV in PB patients, it

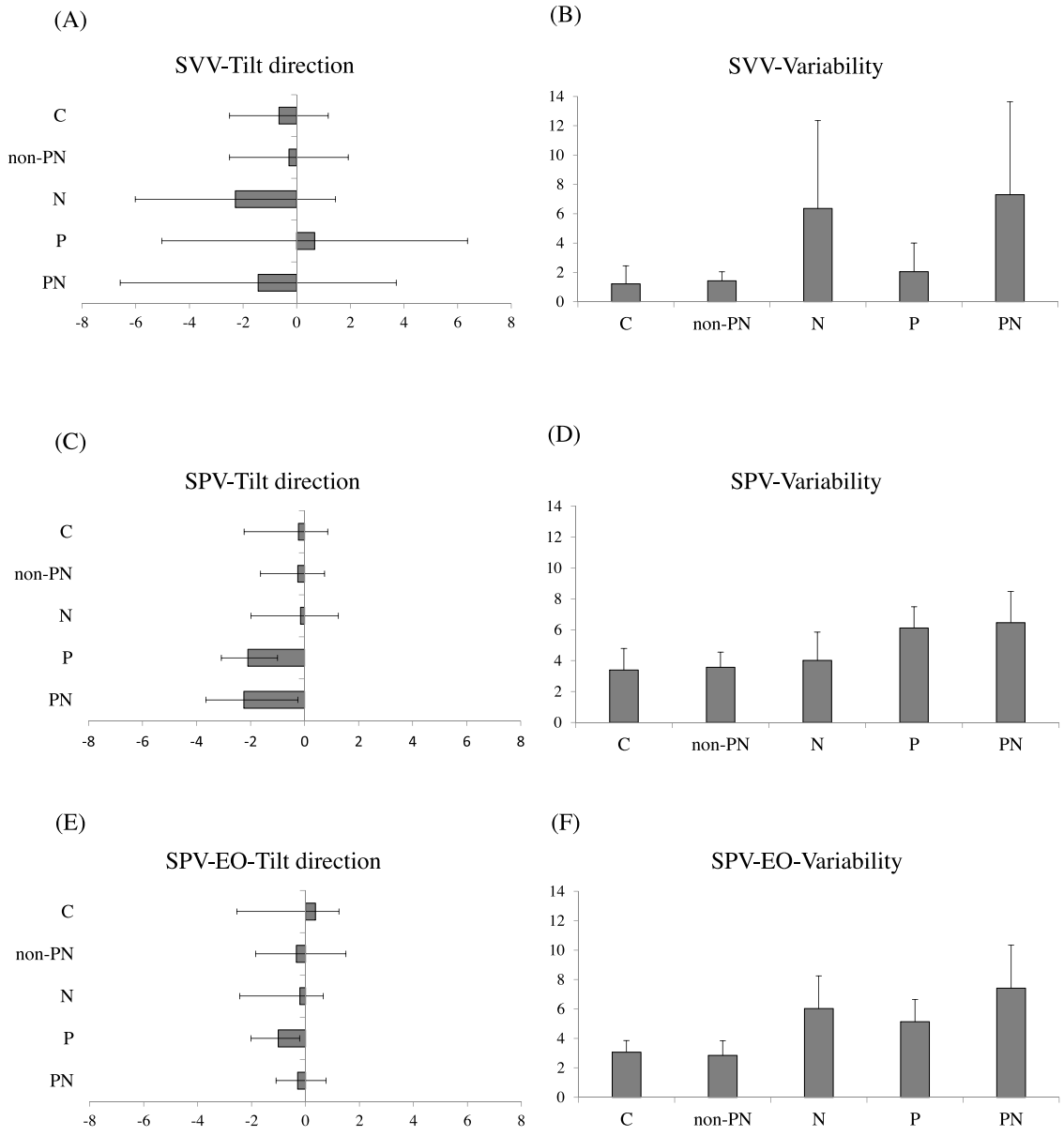

Fig. 2. Results of subjective vertical perception on tilt direction and variability, showing the mean (standard deviation error bars) Negative and positive values on the tilt direction of (A), (C), and (E) indicate a contralesional (stroke patients) or leftward (controls) bias and ipsilesional (stroke patients) or rightward (controls) bias, respectively. (B), (D), and (F) indicate the value of variability.

was also discussed that the vertical distortion of the body perception occurs following a specific posture abnormality. Thus, the PB itself was not only caused by abnormal tilt direction of SPV, but may be caused by other factors. Another limitation was the small sample size across all subgroups of stroke patients; thus, further study should include a larger number of patients. Moreover, PB and USN were defined as being present or absent; thus, the severity of the deficits was not considered. Furthermore, experimental parameters (such as rotation speed and starting angle) may have differed between our SVV and SPV tasks; therefore, the magnitude of bias for each vertical-related parameter cannot be directly compared.

5. Conclusion

In patients with PB, SVV was shown to be different depending on the presence of USN, but SPV might not be affected by USN. In future research, it is necessary to increase the sample size and to conduct longitudinal research to analyze the recovery of vertical perception in these populations.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Contributors

K.F. and K.A. designed the study, and wrote the initial draft of the manuscript. K.F., and K.A. contributed to analysis and interpretation of data, and assisted in the preparation of the manuscript. HK identified the lesion site. All other authors have contributed to data collection and interpretation, and critically reviewed the manuscript. All authors approved the final version of the manuscript.

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Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.neulet.2019.134667.

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