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Research article

Is perception of vertical impaired in individuals with chronic stroke with a history of 'pushing'?

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HIGHLIGHTS

- 'Pushing' is a sign of stroke where the patient leans on the paretic side.
- Pushing behaviour is caused by a misperception of vertical in the roll plane.
- Our work suggests that misperception of postural vertical resolves with recovery of pushing behaviour.
- Impaired perception of visual vertical can persist after pushing symptoms resolve.

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Abbreviations:
BBS, Berg Balance Scale
HP, history of pushing (group)
NIH-SS, National Institutes of Health Stroke Scale
HP, no history of pushing (group)
SCP, Scale for Contraversive Pushing
SNAP, Sunnybrook Neglect Assessment Procedure
SPV, subjective postural vertical
SVV, subjective visual vertical

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ABSTRACT

Post-stroke 'pushing' behaviour appears to be caused by impaired perception of vertical in the roll plane. While pushing behaviour typically resolves with stroke recovery, it is not known if misperception of vertical persists. The purpose of this study was to determine if perception of vertical is impaired amongst stroke survivors with a history of pushing behaviour. Fourteen individuals with chronic stroke (7 with history of pushing) and 10 age-matched healthy controls participated. Participants sat upright on a chair surrounded by a curved projection screen in a laboratory mounted on a motion base. Subjective visual vertical (SVV) was assessed using a 30 trial, forced-choice protocol. For each trial participants viewed a line projected on the screen and indicated if the line was tilted to the right or the left. For the subjective postural vertical (SPV), participants wore a blindfold and the motion base was tilted to the left or right by 10–20°. Participants were asked to adjust the angular movements of the motion base until they felt upright. SPV was not different between groups. SVV was significantly more biased towards the contralesional side for participants with history of pushing ($-3.6 \pm 4.1°$) than those without ($-0.1 \pm 1.4°$). Two individuals with history of pushing had SVV or SPV outside the maximum for healthy controls. Impaired vertical perception may persist in some individuals with prior post-stroke pushing, despite resolution of pushing behaviours, which could have consequences for functional mobility and falls.

1. Introduction

'Pushing' is a sign of stroke whereby the individual leans towards the contralesional side and actively resists attempts to correct to a symmetrical posture [1]. Pushing behaviour affects up to 63% of

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acute [2] and 46% of sub-acute [3] patients with stroke, and can be so severe that the individual cannot sit and/or stand independently, preventing participation in physical rehabilitation [1] and activities of daily living [4]. Prognosis for those with post-stroke pushing is poor; compared to those without pushing, individuals with pushing behaviour have delayed admission to rehabilitation [5], longer lengths of stay [2,5,6] or lower functional outcomes on discharge [6,7], and are less likely to be discharged home [5–7].

It is thought that pushing behaviour arises from misperception of vertical in the roll plane [8,9]. Previously, investigators have measured subjective visual vertical (SVV; i.e. aligning a luminous line with perceived earth vertical) and subjective postural vertical (SPV; i.e. aligning one's body with perceived earth vertical) post-stroke. Findings show that individuals exhibiting pushing behaviours have a contralesional tilt of the SPV [8] and SVV [8,10]. Despite the fact that pushing behaviour appears to resolve within 3–6 months post-stroke [1,2] it is not known if an underlying misperception of vertical persists, even after obvious pushing behaviours resolve. Thus, the purpose of this study was to determine if misperception of vertical persists after pushing behaviour resolves. We expected that recovery of pushing behaviour occurs due to compensatory mechanisms rather than recovery of the underlying perceptual problem; that is, that perception of vertical would be resistant to improvement with recovery from stroke. Therefore, we hypothesized that individuals with prior history of pushing behaviour would show a contralesional tilt of SPV and SVV.

2. Materials and methods

Fourteen individuals with chronic stroke (>6 months post-stroke) were recruited from two sources: (1) former participants in a longitudinal study of stroke recovery; and (2) a database of former stroke patients at the investigators' institution who agreed to be contacted for future research. Participants from the longitudinal study ($n = 6$) completed the Scale for Contraversive Pushing (SCP) early post-stroke and were included if they either: (1) scored ≥ 1 on item C (resists correction) of the SCP early in stroke recovery (e.g. admission to rehabilitation; history of pushing (HP) group); or (2) scored 0 on the SCP early post-stroke (no history of pushing (NHP) group). Participants recruited from the investigators' institution ($n = 8$) were included if they either: (1) had a clear history of "pushing" or "lateropulsion" noted in their hospital charts during acute care (HP group); or (2) no evidence of pushing behaviour noted on their hospital charts (NHP group). All HP and NHP participants had experienced a single stroke event. Ten healthy community-dwelling age-matched (50–85 years old) participants were also recruited (controls). All participants were excluded if, at the time of enrolment, they: (1) had SCP > 0; (2) had any neurological conditions (besides stroke for HP or NHP participants) or musculoskeletal conditions that were likely to affect balance; (3) were unable to communicate in English; and/or (4) had visual acuity worse than 20/50 as tested using a Snellen eye chart. Additionally, participants were excluded if they had prior history of vestibular disorders (e.g. vertigo or dizziness). Controls were excluded if they had Berg Balance Scale (BBS) scores outside the 'normal' range for their age and sex [11]. Past medical history was obtained by hospital chart review (HP and NHP participants) and self-report. The study was approved by the institution's Research Ethics Board and participants provided written informed consent prior to participation.

Data collection occurred during two sessions separated by 1–4 weeks. In the first session, the BBS [12], SCP and Snellen visual acuity tests were conducted for screening purposes. Additionally, the following measures were obtained: age, sex, National Institutes of Health Stroke Scale (NIH-SS [13]; a measure of stroke severity), the Lateropulsion Scale [14], and the Sunnybrook Neglect Assessment Procedure (SNAP; [15]). The Lateropulsion Scale evaluates postural orientation and resistance to correction in lying, sitting, standing, transfers, and walking [14]. Thus, while the SCP is more frequently used in research on pushing behaviour [16], the Lateropulsion Scale provides an additional measure that may be more sensitive to detecting mild pushing behaviour [17]. The SNAP was used to categorize participants according to severity of visuo-spatial neglect; a score <5 indicated no neglect, 5–40 indicated mild-moderate neglect, and >40 indicated severe neglect [15]. Assessments were performed and scored by a physiotherapist. For participants with stroke, time post-stroke and lesion location were obtained from hospital charts.

SPV and SVV were assessed in the second test session; participants were seated restrained in a cushioned chair placed inside a virtual reality motion platform (Fig. 1). Head motion was limited with cushioning and leg motion was limited by footrests [18]. For the SPV, participants were seated in the dark and blindfolded. The motion platform rolled left or right by 10°, 15°, or 20° in the roll plane. One trial was completed for each starting angle in each direction (i.e. 6 trials total); trials were presented in an unpredictable order, alternating between left and right rolls. Once the starting angle had been reached, participants verbally directed the experimenter to tilt the motion base until they felt upright and the final roll angle was recorded. Motion base angular velocity was 0.5°/s and peak acceleration/deceleration was 0.2°/s^2. SPV was the mean of the final roll angle across all 6 trials. For the SVV, participants were seated upright in the chair with eyes open. A white line subtending 3° of visual angle was projected on the screen. Participants were asked to judge if the line would topple to the left or right. A psychometric function was generated from 30 trials using the adaptive staircase procedure QUEST [19,20]. The SVV error was calculated by subtracting the point of subjective equality (i.e. angular bias) of the resulting function from true gravitational upright.

Demographic characteristics and functional balance were compared between the three groups using analysis of variance (ANOVA; age and BBS) or chi-square (sex) tests. Clinical and stroke characteristics were compared between the two stroke groups with ANOVA (time post-stroke, NIH-SS, and SNAP) or chi-square (side of lesion and stroke type) tests. Negative SPV or SVV values are associated with contralesional biases (HP and NHP groups) or leftward biases (controls). To test the primary hypothesis, SPV and SVV were compared between groups with ANOVA. Pre-planned contrasts compared participants with stroke to controls and HP to NHP participants. Additionally, the maximum absolute SPV and SVV values were calculated for controls. Individual stroke participants were considered to have impaired perception if their SPVs or SVVs were outside the maximum for healthy controls. All continuous or ordinal variables were rank-transformed prior to ANOVA. Alpha was 0.05. Values in text are presented as mean [95% confidence interval] for interval data or median [quartiles] for ordinal data.

3. Results

Participant characteristics are shown in Table 1. The three groups did not differ in terms of age ($F_{2,21} = 1.17$, $p = 0.33$) or sex ($\chi^2 = 5.26$, $p = 0.072$). Participants with stroke had worse functional balance than controls (i.e. lower BBS scores; $F_{1,21} = 21.51$, $p = 0.0001$). HP and NHP participants did not differ on lesion side or type of stroke ($\chi^2 < 1.41$, $p > 0.23$). On average, HP participants were recruited later post-stroke (HP: 29.9 [12.3, 47.6] months; NHP: 12.4 [9.0, 15.9] months; $F_{1,12} = 6.23$, $p = 0.028$), had higher SNAP scores (HP: 5 [2,33]; NHP: 0 [0,2]; $F_{1,12} = 7.09$, $p = 0.021$) and had lower BBS scores (HP: 35.6 [20.6, 50.6]; NHP: 53.7 [51.1, 56]; $F_{1,21} = 15.44$, $p = 0.0008$) than NHP participants. There was a trend

Table 1
Participant characteristics. Values for controls are means, with ranges in parentheses, or counts. Data are presented for individual participants with stroke. Negative scores indicate a leftward (controls) or contralesional (HP and NHP groups) deviation from gravity vertical; positive scores indicate a rightward or ipsilesional deviation.

ID	Age (years)	Sex	Time post-stroke (months)	Stroke type	Stroke location	Early SCP score	SNAP score	NIH-SS score	BBS score	SPV (degrees)	SVV (degrees)
	Controls										
	65.3 (55, 79)	Male: 6 Female: 4	–	–	–	–	–	–	55.6 (54, 56)	−0.33 (−3.3, 1.75)	−0.67 (−3.0, 3.0)
	HP group										
A	79	Female	16	Ischaemic	Right parietal & internal capsule	5.25	60[b]	4	37	−5.3[c]	−12.6[c]
B	77	Male	12	Ischaemic	Left periventricular	–	2	3	41	0.9	−4.0[c]
C	80	Male	45	Haemorrhagic	Right thalamus	3	0	1	37	−0.7	−2.5
D	56	Male	15	Ischaemic	Right parietal, frontal & temporal	5.75	30[a]	6	5	2.7	−2.0
E	57	Female	55	Ischaemic	Right middle cerebral artery territory	–	5[a]	2	49	0.4	−1.9
F	66	Male	50	Ischaemic	Right parietal frontal	3	33[a]	8	26	0.8	−1.1
G	72	Male	17	Ischaemic	Right pons	–	3	1	54	−0.1	−1.0
	NHP group										
H	62	Female	17	Ischaemic	Left internal capsule	–	2	1	56	−0.6	−2.0
I	77	Female	8	Haemorrhagic	Right frontal	0	0	0	56	−0.7	−1.0
J	58	Male	12	Ischaemic	Right internal capsule	–	7[a]	1	56	−0.8	−0.6
K	49	Female	16	Ischaemic	Right pons	–	0	2	55	−1.5	0.0
L	66	Female	7	Ischaemic	Left basal ganglia	0	0	2	53	1.7	0.0
M	52	Female	15	Haemorrhagic	Right basal ganglia, thalamus	–	0	2	51	−1.5	0.6
N	69	Female	11	Ischaemic	Left anterior insula, frontal operculum	–	0	1	49	−1.2	2.5

BBS: Berg Balance Scale; HP: history of pushing; NHP: no history of pushing; NIH-SS: National Institutes of Health Stroke Scale, SNAP: Sunnybrook Neglect Assessment Procedure; SPV: subjective postural vertical; SVV: subjective visual vertical.

[a] Mild-moderate hemispatial neglect.

[b] Severe hemispatial neglect.

[c] SVV or SPV outside of the range for healthy control.

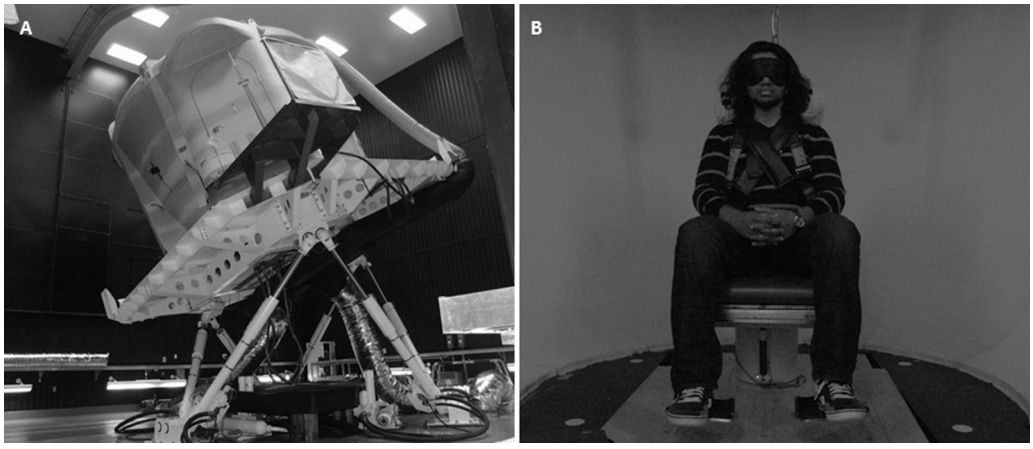

Fig. 1. Laboratory assessment of SPV and SVV.
Participants were seated inside the laboratory, which was mounted on a motion base (Panel A). For assessment of both SPV and SVV, participants were seated upright in a chair (Panel B); participants were strapped into the chair to limit trunk movement, and cushioning limited head movement. For the SPV, participants were blindfolded (as in Panel B). For the SVV, participants had eyes open and faced the curved projection screen.

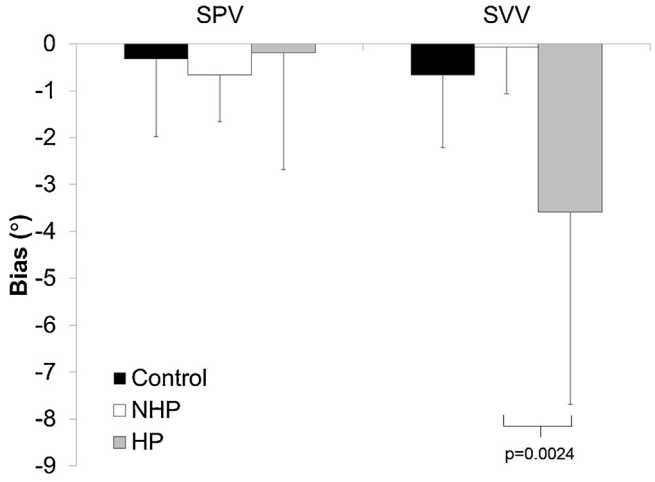

Fig. 2. Mean SPV and SVV for each group.
Values presented are means with standard deviation error bars. Negative values indicate a contralesional (stroke participants) or leftward (controls) bias in perception of vertical. There was no significant difference between groups for the SPV. SVV was significantly more biased towards the contralesional side for HP than NHP participants.

towards higher NIH-SS scores for HP participants than NHP participants (HP: 3 [1,6]; NHP: 1 [1,2]; $F_{1,12} = 4.29$, $p = 0.061$). At the time of the first data collection session all participants, except Participant A (see Table), had Lateropulsion Scale scores of 0; Participant A had a total score of 1. The four HP participants with SCP scores early after stroke all scored ≥ 1 on each SCP item at that time [21].

On average, SPV and SVV were not different between controls and stroke participants (Fig. 2; $F_{1,21} < 1.16$, $p > 0.29$). SPV did not differ between HP and NHP participants (HP: −0.2 [−2.5, 2.1]°; NHP: −0.7 [−1.7, 0.4]°; $F_{1,21} = 2.36$, $p = 0.14$). SVV was significantly more biased towards the contralesional side for HP participants than NHP participants (HP: −3.6 [−7.4, 0.2]°; NHP: −0.1 [−1.4, 1.2]°; $F_{1,21} = 11.94$, $p = 0.0024$). The maximum absolute SPV and SVV for controls were 3.3° and 3°, respectively. Two HP participants had biases in the contralesional direction greater than the maximum for controls; one had both impaired SPV (−5.3°) and SVV (−12.6°) and one had only impaired SVV (−4.0°). No NHP participants had SPV or SVV outside this maximum range for controls.

4. Discussion

These results suggest that individuals with prior history of post-stroke pushing may be more likely to have persisting impairment in perception of visual and postural vertical (generally in the contralesional direction), despite apparent recovery of pushing behaviour. Previous reports have suggested that impaired SPV, but not SVV, is the underlying cause of pushing behaviour [8]. This likely causal relationship is supported by the current work as, overall, there was no difference in SPV between NHP participants and HP participants whose obvious pushing behaviours had resolved, and only one HP participant had a relatively small bias in SPV when compared with other studies [8,21]. While this participant had no sign of pushing when assessed with the SCP, it is interesting that this was the only participant to score >0 on the Lateropulsion Scale and, therefore, may have had very mild sub-clinical pushing behaviours. Thus, this suggests that pushing behaviour and SPV recover concomitantly post-stroke. In contrast to SPV, impaired SVV is more prevalent amongst those with pushing behaviour than those without but is not thought to be causal [8]. It may be noteworthy that the two participants with impaired SVV in the current study were slightly earlier in their stroke recovery than other HP participants (12 and 16 months, compared to an average of 36 months for other HP participants). Thus, it is possible that recovery of pushing behaviour and SPV occurs sooner than recovery of SVV. These hypotheses concerning the profile of recovery of verticality perception and pushing behaviour will need to be supported with longitudinal studies of recovery of pushing, which are currently lacking [1,2].

HP participants had a higher prevalence of visuo-spatial neglect and greater biases in SVV than NHP participants. It is also noteworthy that the individual with the most severe visuo-spatial neglect also had the greatest contralesional biases in SVV. These findings somewhat support the work of others who have reported contralesional biases in SVV amongst individuals with visuo-spatial neglect [22–24]. However, presence of neglect did not fully explain bias in SVV as all other individuals with visuo-spatial neglect (3 HP participants and 1 NHP participant) had SVV within the same range as controls, and the other individual with a large bias in SVV (Participant B; HP group) had no evidence of visuo-spatial neglect. Both the postural disruption underlying pushing behaviour and the disruption of one's egocentric reference frame underlying visuo-spatial neglect may influence perception of visual vertical and, in some cases, may interact to reverse the direction of perceptual biases [23,25]. Thus, both pushing behaviour and visuo-spatial neglect

should be assessed when evaluating the effect of stroke on perception of visual vertical.

We conservatively estimated normative ranges of SPV and SVV using the maximum observed biases within the control group. Our normative ranges (SPV: ±3.3° and SVV: ±3°) were similar, though slightly higher, than reported elsewhere (±2.5° for both SPV and SVV [8]). Had we used this lower threshold to define impaired performance, we would have identified one additional HP participant with an *ipsilesional* bias of SPV (Participant D). However, this threshold would also have determined that two control participants had impaired SPV and two had impaired SVV. It is worth establishing thresholds of SPV and SVV that indicate impaired perception and predict impaired function, rather than relying on thresholds that exceed expected values of healthy controls.

Despite being recruited and assessed later in their stroke recovery, individuals with prior history of pushing behaviour were generally more impaired than those with no history of pushing (i.e. higher prevalence of visuo-spatial neglect, worse functional balance, and trend towards more severe stroke symptoms). This observation supports the findings of others, that individuals with post-stroke pushing have worse outcomes [5,7] and/or more delayed recovery [2,5,26] than those without. Pushing behaviour is typically so severe that individuals cannot sit or stand independently, which delays implementation of physical rehabilitation, such as gait and balance training [2,5,26]. Research around treatment of pushing behaviour is currently lacking [1,27–30]. Therefore, effective interventions should be developed and implemented early in stroke recovery to help these individuals overcome pushing behaviour and improve outcomes for this vulnerable group.

This work has several limitations. While HP and NHP participants were considered to be in the chronic stage of stroke recovery, time post-stroke varied greatly both within and between groups; thus, results may have been influenced by varying levels of recovery amongst participants. Furthermore, while participants had no history of vestibular disorders, we were unable to complete an otoneurological assessment to completely rule out vestibular disorders, which may influence SVV [31]. It is possible that we had limited ability to detect severe SPV with the current experimental design. The maximum starting angle used in the current study was ±20° due to the rotational limits of the simulator; however, some individuals with pushing behaviour can have SPV close to −20° [8]. Others have used starting roll angles of 15–45° [8,21]; more extreme starting angles may be more likely to reveal larger biases in SPV. Finally, from previous studies, we assumed that individuals with a history of pushing behaviour had contralesional tilt of SPV [8] and likely had contralesional tilt of SVV [8,10] early post-stroke. However, contralesional tilts of SPV [21] and SVV [19,21,23,32] have not been consistently reported amongst individuals with pushing behaviour. As SPV and SVV measures early post-stroke were not available for the current set of participants it is not known if recovery of perception of vertical is linked to recovery of pushing behaviour; this will need to be investigated with longitudinal studies.

5. Conclusions

The results of this study suggest that impaired SPV recovers amongst individuals with post-stroke pushing behaviour, but impaired SVV may persist in some individuals. Further longitudinal studies are required to determine the profile of recovery of perception of vertical and postural impairments post-stroke. Additionally, it is of particular interest to determine the effect of continued misperception of vertical on functional mobility and fall risk [18].

Competing interests

The authors declare no conflicts of interest.

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