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Do we need to consider head-on-body position, starting roll position and presence of visuospatial neglect when assessing perception of verticality after stroke?

Charlotte van der Waal[a, b,*], Elissa Embrechts[a, b,c], Steven Truijen[a, b], Wim Saeys[a, b,d]

[a] Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University of Antwerp, Wilrijk, Belgium
[b] Research group MOVANT, Department of Rehabilitation Sciences & Physiotherapy, University of Antwerp, Wilrijk, Belgium;
[c] Department of Experimental Neuropsychology, Helmholtz Institute, Utrecht University, The Netherlands;
[d] Department of Neurorehabilitation, RevArte Rehabilitation Hospital, Edegem, Belgium

*: Corresponding author: Charlotte van der Waal, University of Antwerp, Universiteitsplein 1, 2610 Wilrijk, charlotte.vanderwaal@uantwerpen.be

Abstract

BACKGROUND AND OBJECTIVE

Considering various factors influence the accuracy of the Subjective Visual Vertical (SVV) and Subjective Postural Vertical (SPV), standardization of assessment methods is needed. This retrospective study examined the contribution of Head-on-Body (HOB) position, starting roll position (SRP) and visuospatial neglect (VSN) to SVV and SPV constant errors (i.e., deviation from true vertical). Also, the contribution of HOB position and VSN presence to SVV and SPV variability (i.e., intra-individual consistency between trials) was assessed

METHODS

First-ever unilateral hemispheric stroke survivors (<85 years; <100 days post-stroke) were assessed with three HOB positions (neutral, contralesional and ipsilesional) and seven starting positions (20° contralesional to 20° ipsilesional) of the laser bar and tilt chair. Linear mixed models were selected to evaluate the contribution of HOB, SRP and VSN to SVV/SPV constant errors and variability.

RESULTS

Thirty-four subjects (24 VSN-/ 10 VSN+) were assessed. A tilted HOB position led to significantly higher constant errors for the SVV and SPV (latter only in the VSN- group), and an increased SVV variability. SRP only significantly contributed to the SVV constant errors and only in the VSN- group. Furthermore, VSN presence resulted in a significantly higher SVV and SPV variability.

CONCLUSIONS

HOB position, SRP and VSN presence are important factors to consider during SVV and SPV measurements. Assessment with a neutral HOB position leads to more accurate results. HOB position and SRP influence the results of the SVV and SPV differently in individuals with and without VSN, which highlights the relevance of VSN assessment.

Keywords: stroke, verticality perception, visual vertical, postural vertical, spatial cognition, visuospatial neglect

Introduction

For a correct vertical alignment of the body in relation to the true vertical (i.e., gravitational vector), one should be able to both accurately perceive verticality and react to this perceived vertical with an accurate motor response [1, 2]. The true vertical is defined as the trajectory of a weight falling to the ground [3]. The perception of this true vertical is suggested to be derived from an internal model of verticality, based on the convergence and integration of multisensory input in the parietotemporal cortical areas [2, 4]. This afferent information is coming from the head-in-space (otoliths), head-on-body (neck proprioceptors) and body-in-space ('somaesthetic graviceptors') [5-7]. During convergence of this information, the brain uses all available signals, accompanied with an unavoidable degree of uncertainty due to noisy sensory input [5, 6, 8]. This uncertainty can be reduced by weighting the sensory input in proportion to its reliability [6, 8, 9].

A stroke may cause a biased construction of the internal reference of verticality due to impaired sensory input or processing [8]. Consequently, stroke subjects might perceive themselves in an upright position, even when their posture is truly tilted towards a disturbed internal reference of verticality. In severe cases, this could lead to lateral postural disorders (e.g., lateropulsion) [1, 10, 11]. Considering the known relationship between inaccurate perception of verticality and decreased balance performance, an in-depth understanding of what contributes to this misperception is needed [12, 13].

Verticality perception is evaluated within different modalities, including the Subjective Visual Vertical (SVV) and the Subjective Postural Vertical (SPV) [10]. During SVV measurements, subjects are asked to align a tilted visual line or object with the gravitational vector using only visual input [14]. During SPV measurements, a seated and blindfolded individual is being tilted in a tilting chair and asked to indicate when they perceive themselves as being upright [10]. The accuracy of their estimation is based on the constant error (i.e., deviation between estimation and gravitational vector) and the variability (i.e., intra-individual consistency between trials, see Methodology).

Given the absence of an established gold standard, a range of assessment tools to evaluate the perception of verticality have been employed [10, 14-16]. This has resulted into a notable degree of variability and heterogeneity in the results reported in prior studies. One plausible explanation for this variance could be the lack of knowledge of influencing factors. One such factor is the Head-on-Body (HOB) position, referring to the position of the head in relation to the trunk [17, 18]. Similarly, the starting roll position (SRP), denoting the starting angle of the SVV line or the tilting chair in case of the SPV, also appears to have an influence [17]. Moreover, the utilization of varying calculation methods to determine both the constant error and variability of the measurement adds to the divergence in reported findings [14]. These factors may lead to heterogeneity in results [10, 14-16].

Apart from these methodological aspects, spatial cognitive disorders, such as visuospatial neglect (VSN), may negatively impact verticality perception [15, 16]. VSN occurs in 23% to 48% of stroke survivors during the acute phase after stroke [19, 20]. A recent systematic review shows that VSN is associated with larger SVV errors and variability. Findings for the SPV were inconclusive, likely due to the fact limited number of studies investigating this [16]. Consequently, it is of interest to further analyse the contribution of VSN to constant errors and variability of both the SVV and SPV.

It is generally assumed that the abovementioned factors influence the SVV and SPV. Yet, no study has systematically evaluated the contribution of the HOB position, SRP and VSN altogether to the SVV and SPV outcomes in stroke survivors. Hence, this study evaluates the contribution of:

- HOB position, SRP and VSN to the constant errors of the SVV and SPV;
- HOB position and VSN to the variability of the SVV and SPV.

Methods

Ethical approval for this study was given by the Ethics Committee (registration number B300201630358), University Hospital Antwerp, Belgium, in accordance with the Declaration of Helsinki. The protocol is registered online (ClinicalTrials.gov identified: NCT03019432). The study is written based on the STROBE statement (see Appendix A) [21].

Subjects

This retrospective study involves a primary analysis of data collected between January 2009 and July 2009. During this period, individuals consecutively admitted to Hof Ter Schelde Rehabilitation facility in Antwerp, Belgium underwent eligibility assessment for participation. The criteria for eligibility included: (1) confirmation of a first-ever unilateral hemispheric stroke through CT and/ or MRI, (2) age between 18-85 years, (3) assessment within the initial 100 days following the stroke, (4) (corrected to) normal visual acuity, (5) absence of brainstem or cerebellar lesions, (6) no non-stroke related or communication disorders that could interfere (e.g. orthopaedic, peripherical, vestibular or neurological), and (7) a requirement of achieving and maintaining a minimum range of motion of 35° for head movement in relation to the upright sternum (measured with a goniometer). The neuropsychologist who supervised the subject evaluated the presence of VSN, based on the Behavioral Inattention Test (conventional subtests). The subjects were considered to suffer from VSN, if the total score on the combination of six pen-and-paper tasks was below the cut off score of 129 [22]. The presence of lateropulsion was assessed using the Scale of Contraversive Pushing, evaluating postural symmetry in the frontal plane, use of non-paretic extremities and resistance to passive correction. The original cut-off score (>1 for each section) was used [23]. Prior to inclusion, the subjects were asked to sign a written informed consent.

Assessment of the SVV and SPV

Devices

The used devices and protocol were similar to previous studies evaluating the SVV and SPV [8, 17, 24]. The SVV was assessed using the Difra Vertitest (Difra, Belgium, Type DI072010) with an accuracy of 0.1°. Subjects sat upright with their feet on the ground in a dark room, 2.5 metre away from the wall where a 1-metre laser bar was projected. Subjects with decreased sitting balance were assessed in a wheelchair, otherwise a chair without arm or back rests was used. For SPV measurements, blindfolded subjects sat on a tilting chair with a hard backrest, side rests, safety belt, and non-skid layer on the seating surface (see Figure 1). The chair tilted in the frontal plane using hydraulic pumps controlled by the examiner via a remote control. A digital inclinometer was placed on the back of the chair with an accuracy of 0.01°.

Procedure

After a 5-minute habituation to the dark, the examiner tilted the laser bar (SVV) or tilting chair (SPV) towards a specific SRP. The subject used the less-affected hand to operate the remote control (which provided no haptic information) to the position they perceived as vertical. Subjects did not receive feedback about their performance during the assessment. The experiments lasted about 60 minutes.

Three HOB positions were assessed. The ***neutral HOB*** position, in which the head is in line with the trunk (both in upright position). During the ***contralesional*** and ***ipsilesional HOB*** position, the subject is asked to tilt their head as far as possible to respectively the opposite and same site of the brain lesion while keeping the trunk upright. HOB position was tactilely controlled by the examiner to decrease variability in HOB position. A range of motion of the head in relation to the sternum between 35° and 45° was pursued. Seven different ***SRPs*** of the laser bar or the tilt chair were used in a random order (20°, 10° and 5° both in contralesional/ ipsilesional direction and 0°). These SRPs were examined once with every HOB position.

Terms and definitions

The ***constant error*** (or 'error') reflects the difference between the perceived vertical and the gravitational vector, with the direction (ipsi- vs contralesional) considered (see Figure 2). Negative values correspond to an error in contralesional direction, whereas positive values correspond to errors in ipsilesional direction. Furthermore, the ***variability*** (i.e., uncertainty) reflects the intra-individual variability (standard deviation of the trials) and gives an indication of the robustness of the measurement. Higher variability between measurements in one individual indicates that the subject is more uncertain about the vertical position [14].

Statistical analysis

Descriptive statistics (e.g., mean and standard deviations) were performed and the Mann Whitney U test was used to evaluate between-group differences in demographic data.

To address constant errors, a primary analysis employed a linear mixed model with SVV or SPV errors as dependent variables. A random intercept for 'individual' was included to account for repeated measures. Independent variables encompassed VSN, HOB position, SRP and their interactions ('HOB position * SRP', 'HOB position * neglect', 'SRP * neglect'). Notably, the primary analysis revealed a significant interaction effect ('HOB position * neglect'), signifying varied HOB effects for subjects with and without VSN (respectively VSN+ and VSN-). Consequently, a secondary analysis was conducted. For VSN+ and VSN- subjects, separate model analyses were performed for the SVV and SPV. The same model architecture was used, however, independent variables were now HOB position, SRP and HOB position * SRP. Graphs were selected to visualize the results. Variability was calculated using the intra-individual standard deviation of the seven trials. A linear mixed model was selected with SVV or SPV variability as dependent variables. A random intercept for 'individual' was added, and HOB position, VSN, and their interaction were entered as fixed effects.

Post-hoc analyses were conducted for HOB position on errors and variability using Dunnett's post-hoc test. We inspected histograms and Q-Q plots of residuals to confirm model assumptions, which were met. Graphs were used to visualize the results. All analyses were conducted using JMP Pro® version 16.

Results

Demographics

Table 1 shows that 34 individuals with stroke (17 males) were included, with a mean age of 62.21±12.61 years. The subjects were assessed between 13 and 99 (44.91±23.57) days post-stroke. Whereas 10 out of 34 subjects suffered from VSN, none showed lateropulsion. Age and days post-stroke were not different between the VSN- and VSN+ groups (resp. P=.636, P=.664).

The Subjective Visual Vertical

Constant error

In Table 2 the SVV errors are listed regarding HOB, SRP and the presence of VSN. There was a significant interaction between HOB and VSN (F=23.27, P<.001), indicating that the effect of HOB position differed between VSN+ and VSN- subjects. Consequently, separate analyses were conducted for each group. Figure 3 visualized the SVV errors in relation to the SRP, HOB position and VSN.

VSN- group

SRP and HOB position were significant predictors of SVV errors (resp. F=18.34, *P*<.001; F=115.18, *P*<.001). However, no significant 'SRP x HOB position' effect was found (*P*=.199). The β-estimates of the separate SRPs and HOB positions are shown in Table 3. Compared to the neutral HOB position, a contralesional HOB position (MD = 4.00°, SE=0.63, CI=[2.74; 5.26, *P*<.001) and ipsilesional HOB position (MD=-4.98°, SE=0.63, CI=[-6.24; -3.72, *P*<.001) resulted in significantly greater errors.

VSN+ group

HOB position was a significant predictor for SVV error (F=43.63, *P*<.0001), whereas the SRP was not (F=1.02, *P*=.413). The β-estimates of the separate SRPs and HOB positions are shown in Table 3. A contralesional (MD=10.72°, SE=2.14, CI=[5.93; 15.50], *P*<.001) and ipsilesional HOB position (MD=-9.72°, SE=2.14, CI=[-14.51; -4.94], *P*<.001) resulted in a significant greater error compared to a neutral HOB position. Table 4 provides the Least Squares Means Estimates of both the VSN- and VSN+ groups.

SVV variability

Figure 4A visualized the SVV variability in relation to the HOB position and VSN. When all subjects are considered, HOB position and the presence of VSN were both predictors to the SVV variability (resp. F=4.227, P=.020, F=8.005, P=.009). However, no significant 'HOB position x VSN' was found (p>0.05). Table 2 shows the variability for every HOB position, for both the VSN- and VSN+ group.

SVV variability was estimated higher in VSN+ subjects compared to VSN- subjects (MD=-3.80°, SE=1.34, CI=[1.04; 6.55], P=.009) (see Table 3). Concerning HOB position, the contralesional HOB position resulted in significant greater errors compared to a neutral HOB position (MD=2.09°, SE=0.81, CI=[0.23; 3.94], P=.026), whereas an ipsilesional HOB position did not (MD=0.01, SE=0.81, CI=[-1.84; 1.87], P=1.00).

The Subjective Postural Vertical

Constant errors

In Table 2 the SPV errors regarding HOB, SRP and the presence of VSN are listed. There was a significant interaction between HOB and VSN (F= 3.35, *P*=.036), indicating that the effect of HOB position differed between VSN+ and VSN- subjects. To further investigate this, separate analyses were conducted for each group. Figure 5 visualized the SPV errors in relation to the SRP, HOB position and VSN.

VSN- group

HOB position significantly contributed to the SPV errors (F=13.81, P<.0001). Contrary to the SVV in VSN- subjects, no significant contribution to the different SRPs was found (F=.66, P=.683). The β-estimates of the separate SRPs and HOB positions are shown in Table 3.

An ipsilesional HOB position resulted in a significantly lower error (MD = -1.14°, SE=0.24, CI=[-1.67; -0.61], P<.0001) compared to a neutral position (mean constant error 0.69°), whereas a contralesional HOB position did not (MD = -0.09°, SE=0.24, CI=[-0.62; -0.45], P=.910, see Table 3).

VSN+ group

Both HOB and SRP did not lead to significant differences in SPV estimation (resp. F=1.82, P=0.166; F=0.105, P=0.996). Table 4 provides the Least Squares Means Estimates of both the VSN- and VSN+ groups.

SPV variability

Figure 4B visualized the SVV variability in relation to the HOB position and VSN. In Table 2 the SPV variability of both groups are listed. For all subjects together, VSN was a predictor for SPV variability (F=18.051, P=.0002). However, the contribution of the HOB position was not significant (F=2.992, P=.059).

Similar to the SVV, the variability was higher in VSN+ subjects compared to the VSN- group (MD=2.96°, SE=0.697, CI=[1.54;4.38], P=.002) (see Table 3).

Discussion

This study shows that the HOB position and SRP are important factors to consider when evaluating verticality perception after stroke. The contribution of these factors were different for the VSN+ and VSN- groups when evaluating SVV and SPV errors. This highlights the importance of assessing VSN when evaluating verticality perception. Regarding methodological approaches, the HOB position was a significant contributor to the SVV error in both groups, but only to the SPV in the VSN- group. The SRP led to significant differences in the SVV error within the VSN- group, whereas it did not contribute to the results of the SPV in either groups. With regards to variability, the contribution of these factors were similar for both groups. VSN presence led to increased SVV and SPV variability, and a tilted HOB position led to an increased SVV variability.

Although the SVV errors of the VSN+ group were higher than those of the VSN- group (respectively 0.94° and -0.18° (within a neutral HOB position)), both were within the normative range as described in previous studies (-2.5 to 2.5° [1, 14]). This is in contrast to a recent systematic review, which associated VSN presence with higher constant errors and variability [16]. In contrast to the neutral HOB position, during head tilts, SVV errors in both groups exceeded the normative range. Therefore, in individuals who are unable to maintain a neutral HOB position, a false positive result may occur. This could be wrongly assumed as an SVV misperception. For valid SVV measurements, controlling the head within a neutral position seems to be key, for instance by fixation. Furthermore, the mean SVV error tended to deviate towards the opposite side of the HOB position. For instance, during a contralesional

HOB position, the SVV was estimated ipsilesional and vice versa. This phenomenon, known as the 'E-effect', indicates that the head-in-space orientation significantly influences the error direction during both the SVV and SPV. This is attributed to an overestimation of the direction of the earth vertical direction [8, 25, 26]. However, previous studies showed that this effect is seen when the HOB tilt is <60-70°, but a HOB tilt >60-70° leads to the opposite effect. In this case, an underestimation of the earth vertical is seen. In other words, the constant error is deviated toward the HOB tilt position (known as the 'A-effect') [27]. These findings collectively underscore the necessity of measuring the SVV with a neutral HOB position to accurately determine the direction of errors.

Similar to the SVV, SPV errors (VSN-: 0.69°, VSN+: -1.25°) measured with a neutral HOB position were within previously established normative ranges (0.12°, SD: +/- 1.49°) [1, 14]. Whereas SVV errors exceed the normative range when measured with a tilted HOB position, this is not the case for the SPV (except for the ipsilesional HOB position within the VSN+ group, which does exceed the normative range). This might stem from distinct input sources used to estimate the SVV and SPV. The SVV primarily relies on visuo-vestibular information, while the SPV relies on graviceptive-somaesthetic information [10]. According to prior studies, the head-in-space signal is sensed directly by the otoliths, but also indirectly by combining head-on-body and body-in-space signals [5, 6]. During HOB tilt, there is a bias of vestibular input due to otolithic noise, necessitating greater reliance on somatosensory input [8]. However, also the somatosensory input is altered by the HOB tilt, caused by stretching of the neck proprioceptors opposite to the head tilt [28]. Consequently, both the direct (otoliths) and indirect (neck proprioceptors) indicators of head-in-space orientation are compromised, resulting in biased available information. Considering these sources are mainly needed to perceive the visual vertical, the HOB position predominantly influences the SVV rather than the SPV.

Also the SRP is relevant to consider, given that certain SRPs led to greater SVV errors in the VSN- group than others. This phenomenon has been observed in healthy individuals as well [17, 29]. Contrary to the results of this study, in healthy individuals this impact is seen for both the SVV and SPV errors [17]. Figure 3 illustrates a linear relationship between constant errors and the SRP in the VSN- group, which remains relatively consistent across the three HOB positions. This was not the case for the VSN+ group, potentially due to trial-related uncertainty (i.e., higher variability). In line with previous studies [30-32], this study demonstrates higher SPV and SVV variability in VSN+ subjects, which suggests higher degree of uncertainty regarding the position of the true vertical. This is likely the result of inattention to the contralesional hemispace and/or deficits in processing multisensory input, leading to a biased internal reference of verticality regardless of the initial SRP.

Implications for future research and clinical practice

Given that the SRP and HOB position are important factors to consider when measuring verticality perception after stroke, future studies should focus on a standardized protocol for evaluating the SVV and SPV. As many stroke survivors suffer from head malalignment [33], the knowledge of this study is relevant for future research and evaluation in clinical practice. Notably, a tilted HOB position compromises the accuracy of both SVV and SPV estimations. Thus, it is recommended to assess SVV and SPV with a neutral HOB position to obtain the most reliable and valid estimations. Given that certain SRPs lead to larger constant errors than others, it is recommended to vary in SRP and its direction when conducting assessment. Additionally, reporting errors based on the SRP rather than averaging across random positions should be considered. As VSN presence contributes to verticality perception, VSN assessment is crucial, particularly within the subacute post-stroke phase (i.e., first three months post-stroke) when VSN is highly prevalent [19, 20]. As there is limited understanding of the recovery of (mis)perception of verticality following stroke, future studies should focus on longitudinally evaluating verticality perception for an in-depth understanding of a biased internal reference of verticality. This information could help in establishing rehabilitation strategies to improve this internal reference. Prior studies addressed the necessity to evaluate other post-stroke comorbidities such as lateropulsion [15]. Since this study was unable to include subjects with lateropulsion, future investigations should explore the impact of HOB position and SRP within this population.

Limitations of the study

There are several limitations in this study. Firstly, lateropulsion and VSN presence were assessed by the supervising psychologist rather than by the examiners. Although assessment was based on the Behavioral Inattention Test [22] and the Scale for Contraversive Pushing [23], individual scores of these tests/ items were not accessible, which would have been interesting for further analyses. For the Scale of Contraversive Pushing only the presence of absence (‘present’ or ‘absent’) was noted, based on the conventional score [23]. Therefore, it was not possible to revise the score to the modified cut-off score suggested by Baccini and colleagues [34]. Also, if the study was performed nowadays, the Burke Lateropulsion Scale would be used as well to detect lateropulsion, as it might be more sensitive to detect mild lateropulsion and evaluates the condition during functional tasks (e.g., during transfers) [35, 36]. Although none of the participants expressed difficulty in maintaining a tilted HOB position, it might pose challenges for severely disabled subjects. For future standardization purposes, employing a neck collar to control head position (neutral or tilted) could be beneficial. The protocol and set-up for the assessment of the SVV and SPV used in this study are not according a gold standard, given the absence of such a standard. Nevertheless, similar set ups to our study have been used in previous studies [8, 17, 24]. Furthermore, during the SVV, some subjects were assessed in a wheelchair with back support and others on a chair without back support. This might have impacted the results. In futures studies, it is recommended to assess all subjects with back support.

Conclusion

A tilted HOB position resulted in increased errors of the SVV, increased errors of the SPV (in VSN- group only) and heightened SVV variability. This emphasizes the necessity of controlling the head in a neutral position during SVV and SPV assessments. Also, SRPs are relevant to consider, since they may lead to higher errors of the SVV (observed in VSN- group only). HOB position and SRP influence the results of the SVV and SPV differently in VSN- and VSN+ subjects. Given the contribution of VSN presence to heightened SVV and SPV variability, VSN assessment for clinical and research purposes is key.

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Disclosure of interest

The authors report there are no competing interests to declare.

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Figures

Figure 1. Tilt chair used for Subjective Postural Vertical assessment

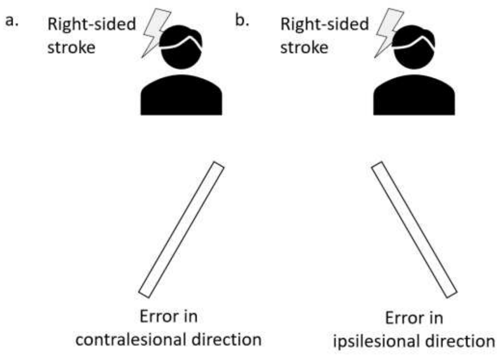

Figure 2. Example to illustrate an ipsilesional or contralesional direction during the SVV.

a) Subject with right-sided stroke perceives the line as vertical when the line is tilted counterclockwise from his/ her point of view. In relation to the brain lesion, the error is in contralesional direction.
b) In this scenario, the subject perceives the line as vertical when tilted in clockwise direction from his/ her point of view. This error is in ipsilesional direction, in relation to the brain lesion.

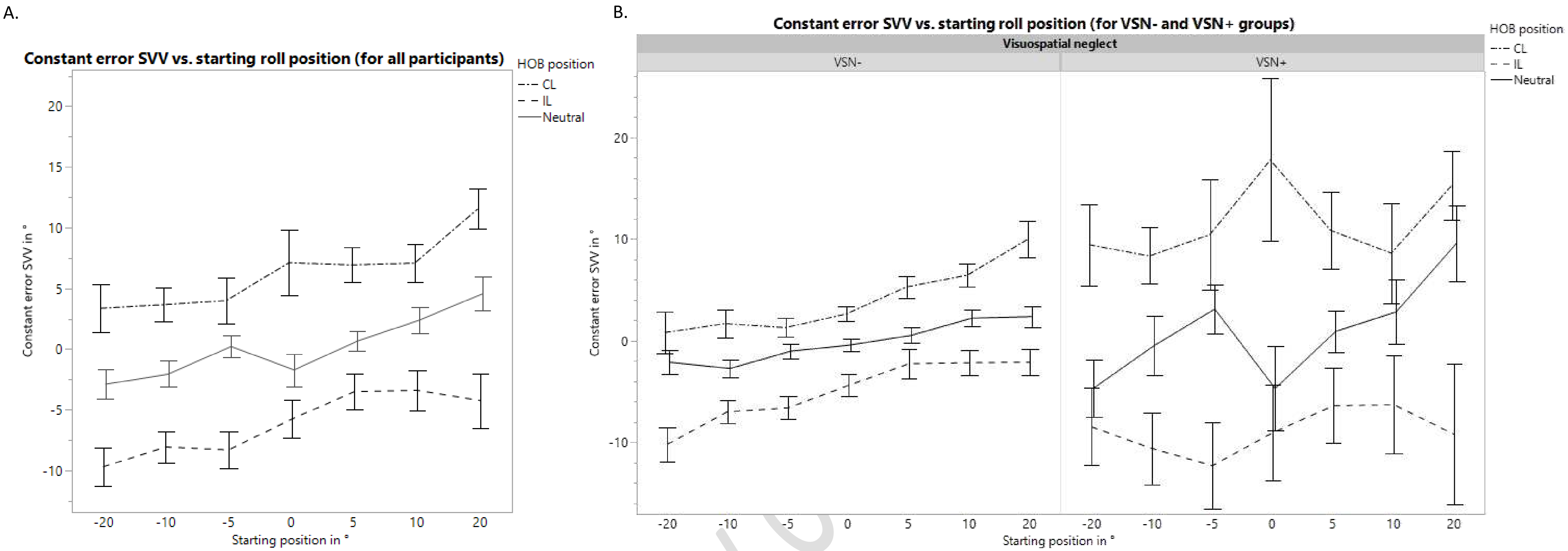

Figure 3. A. Visualisation of the SVV constant error, in relation to SRP and HOB position. B. Visualisation of the SVV constant error, in relation to SRP, HOB position for the VSN- group and the VSN+ group. * The vertical line represents the error bar, which is constructed one standard error from the mean.

CL: contralesional, IL: ipsilesional, HOB: Head-on-Body, SVV: Subjective Visual Vertical, VSN-: group without visuospatial neglect subjects, VSN+: group with visuospatial neglect subjects.

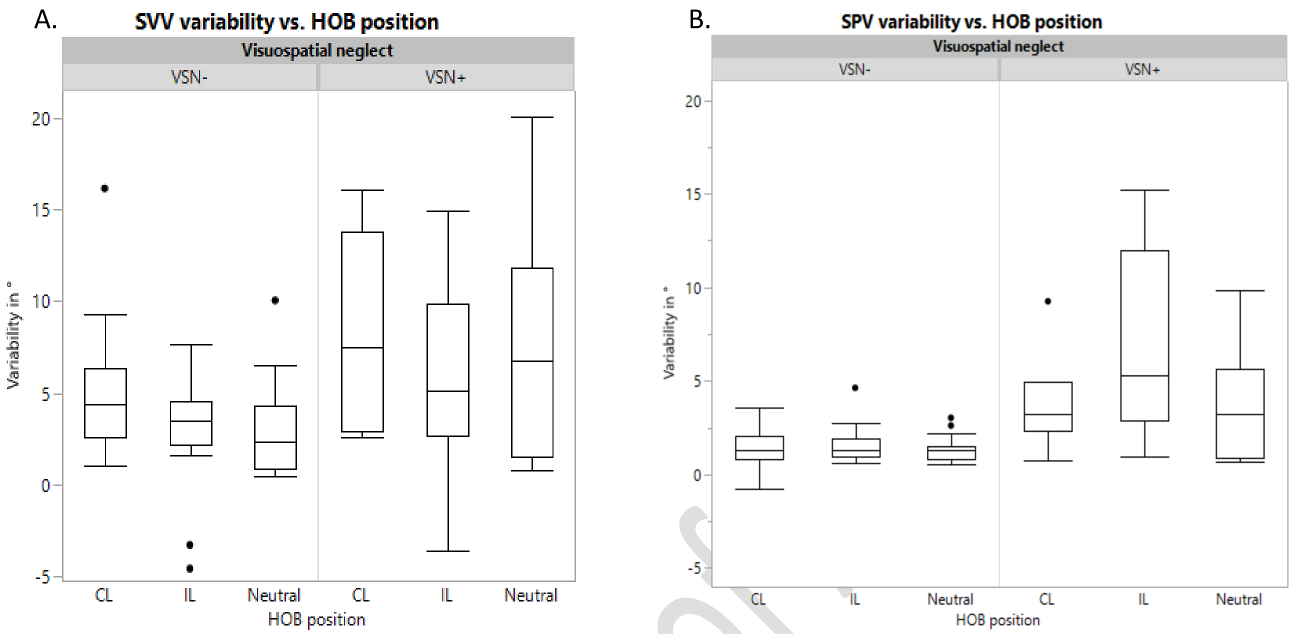

Figure 4. Visualisation of the SVV (A.) and SPV (B.) variability in relation to the HOB position in subjects with and without VSN.

CL: contralesional, IL: ipsilesional, HOB: Head-on-Body, SVV: Subjecive Visual Vertical, SPV: Subjective Postural Vertical, VSN-: group without visuospatial neglect subjects, VSN+: group with visuospatial neglect subjects.

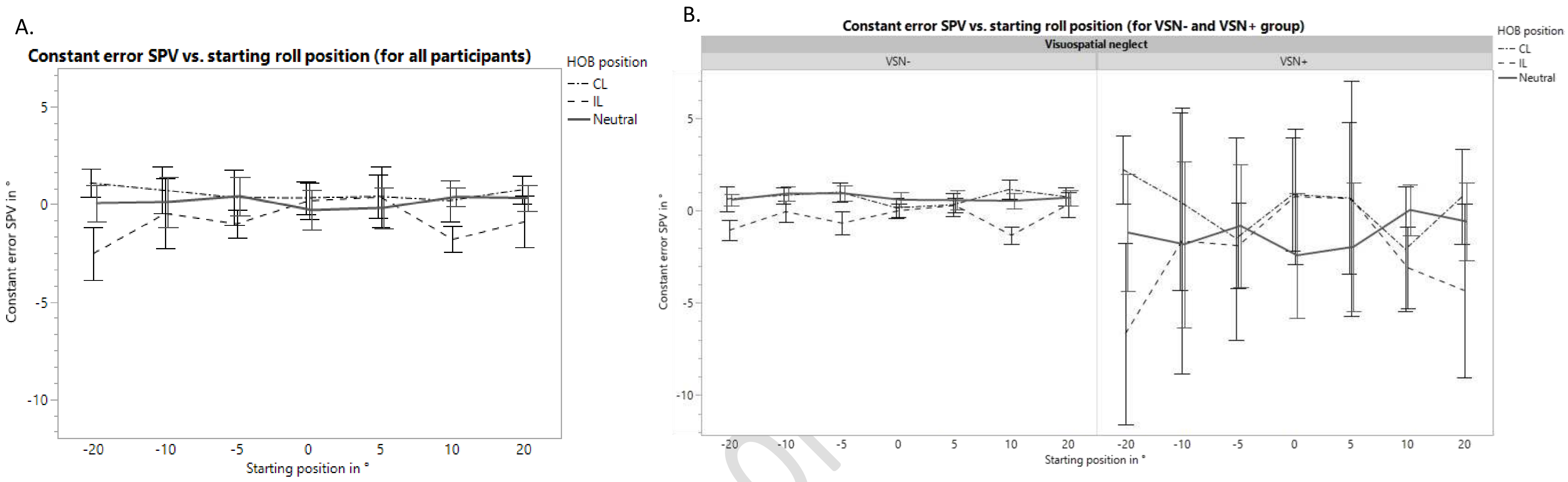

Figure 5. A. Visualisation of the SPV constant error, in relation to SRP and HOB position. B. Visualisation of the SVV constant error, in relation to SRP, HOB position for the VSN- group and the VSN+ group. * The vertical line represents the error bar, which is constructed one standard error from the mean.
CL: contralesional, IL: ipsilesional, HOB: Head-on-Body, SPV: Subjective Postural Vertical, VSN-: group without visuospatial neglect subjects, VSN+: group with visuospatial neglect subjects.

Tables

Table 1. Characteristics of included subjects.

	All subjects	VSN+	VSN-
N	34	10	24
Age in years (SD)	62.2 (12.6)	60.5 (13.5)	62.9 (12.5)
Gender	17 F/ 13 M	5 F/ 5 M	12 F/ 12 M
Lesion side	18 R/ 16 L	9 R/ 1 L	9 R/ 15 L
Time post-stroke in days (SD)	44.91 (23.57)	45.6 (19.4)	44.6 (25.5)
Type of stroke	5 H/ 29 I	2 H/ 8 I	3 H/ 21 I

F: female; H: haemorrhagic stroke; I: ischemic stroke; N: number of subjects; L: left; M: male; R: right; VSN: visuospatial neglect (+ = present, - = not present).

Table 2. Constant errors and variability of the SVV and SPV regarding SRP, HOB position and presence of VSN

		SVV (mean constant error or variability in ° (SD)						SPV (mean constant error or variability in ° (SD)					
		VSN-			VSN+			VSN-			VSN+		
	HOB position	CL	N	IL	CL	N	IL	CL	N	IL	CL	N	IL
		Constant error											
SRP	Overall error	4.01 (6.59)	-0.18 (4.55)	-4.97 (6.22)	11.53 (13.50)	0.94 (10.50)	-8.91 (12.56)	0.69 (2.22)	0.69 (1.93)	-0.37 (2.23)	0.19 (8.76)	-1.25 (9.13)	-2.32 (11.18)
	20° CL	0.80 (8.81)	-2.13 (5.82)	-10.22 (7.30)	9.44 (11.30)	-4.66 (8.93)	-8.48 (10.74)	0.63 (2.72)	0.58 (1.54)	-1.07 (2.22)	2.22 (4.91)	-1.19 (9.56)	-6.67 (12.08)
	10° CL	1.67 (5.96)	-2.74 (4.27)	-6.99 (4.75)	8.34 (7.83)	-0.48 (9.31)	-10.61 (9.96)	0.82 (1.83)	0.93 (1.85)	-0.06 (2.39)	0.50 (11.77)	-1.82 (13.48)	-1.65 (17.62)
	5° CL	1.28 (4.03)	-1.05 (3.54)	-6.62 (5.02)	10.44 (15.52)	3.11 (7.57)	-12.30 (12.00)	1.00 (2.18)	0.93 (1.96)	-0.68 (2.60)	-1.51 (13.44)	-0.82 (10.03)	-1.90 (5.65)
	0°	2.63 (3.10)	-0.42 (2.92)	-4.40 (4.54)	17.78 (22.63)	-4.70 (13.24)	-9.05 (13.22)	0.15 (2.29)	0.58 (1.85)	-0.01 (1.55)	0.87 (7.50)	-2.42 (10.13)	0.75 (8.98)
	5° IL	5.29 (4.67)	0.53 (3.55)	-2.27 (6.41)	10.84 (10.68)	0.91 (6.58)	-6.41 (10.50)	0.31 (2.48)	0.56 (2.48)	0.28 (1.62)	0.68 (10.10)	-1.96 (10.40)	0.65 (15.64)
	10° IL	6.44 (4.88)	2.21 (4.02)	-2.18 (5.36)	8.61 (13.93)	2.83 (9.99)	6.30 (13.56)	1.14 (2.15)	0.53 (1.97)	-1.34 (1.98)	-2.09 (8.94)	0.03 (4.16)	-3.10 (5.42)
	20° IL	9.96 (7.83)	2.37 (4.87)	-2.13 (5.60)	15.28 (9.63)	9.59 (11.78)	-9.21 (19.51)	0.76 (2.02)	0.70 (1.95)	0.32 (2.76)	0.74 (6.29)	-0.59 (6.28)	-4.33 (11.49)
		Variability											
		5.06 (3.44)	2.88 (2.44)	3.13 (2.93)	8.21 (5.37)	7.65 (7.08)	5.77 (5.74)	1.41 (1.04)	1.34 (0.65)	1.57 (0.98)	4.05 (2.71)	3.71 (2.99)	6.87 (5.26)

CL: contralesional, HOB: Head-on-Body, IL: ipsilesional, N: neutral, SD: Standard Deviation, VSN+: subjects with visuospatial neglect, VSN-: subjects without visuospatial neglect.

Table 3. Linear Mixed Models with estimates, standard errors, P-values and 95% confidence intervals for the SVV and SPV constant errors and variability

	SVV								SPV							
	VSN-				VSN+				VSN-				VSN+			
	β-estimate	SE	*P*-value	95% CI	β-estimate	SE	*P*-value	95% CI	β-estimate	SE	*P*-value	95% CI	β-estimate	SE	*P*-value	95% CI
	Constant errors															
Intercept	-1.28	0.85	0.133	[-2.96; 0.39]	-4.40	2.93	0.138	[-10.24; 1.45]	-0.22	0.36	0.551	[-0.94; 0.50]	-1.38	2.92	0.641	[-7.48; 4.71]
SRP 20° CL	-7.07	0.88	**<.001***	[-8.79; -5.35]	-7.05	3.21	**0.030***	[-13.39; -0.71]	-0.51	0.35	0.154	[-1.20; 0.19]	-0.47	2.13	0.827	[-4.69; 3.755]
SRP 10° CL	-6.02	0.88	**<.001***	[-7.74; -4.30]	6.44	3.21	**0.047***	[-12.78; -0.10]	-0.01	0.35	0.98	[-0.71; 0.69]	0.17	2.15	0.939	[-4.09; 4.27]
SRP 5° CL	-5.39	0.88	**<.001***	[-7.11; -3.67]	-4.93	3.21	0.127	[-11.27; 1.41]	-0.14	0.35	0.693	[-0.84; 0.56]	-0.05	2.15	0.981	[-4.1; 4.21]
SRP 0	-4.04	0.88	**<.001***	[-5.76; -2.33]	-4.68	3.21	0.147	[-10.19; 2.50]	-0.33	0.35	0.350	[-1.03; 0.37]	0.7	2.15	0.746	[-3.56; 4.96]

SRP 5 IL	-2.2	0.88	**0.013***	[-3.91; -0.48]	-3.84	3.21	0.233	[-11.02; 1.67]	-0.2	0.35	0.565	[-0.90; 0.49]	0.82	2.15	0.706	[-3.45; 5.08]
SRP 10 IL	-1.17	0.88	0.181	[-2.89; 0.55]	-3.75	3.21	0.244	[-10.10; 2.59]	-0.46	0.35	0.199	[-1.15; 0.24]	-0.36	2.13	0.865	[-4.58; 3.85]
Head position (CL, N, IL)	8.98	0.59	**<.001***	[7.82; 10.15]	20.44	2.19	**<.001***	[16.12; 24.76]	1.05	0.24	**<.001***	[0.58; 1.53]	2.45	1.51	0.107	[-0.53; 5.44]
Head position (CL, N, IL)	4.81	0.58	**<.001***	[3.66; 5.95]	9.72	2.14	**<.001***	[5.50; 13.95]	1.14	0.24	**<.001***	[0.67; 1.61]	0.02	1.5	0.992	[-2.96; 2.99]
Variability																
	β-estimate	SE	*P*-value	95% CI					β-estimate	SE	*P*-value	95% CI				
	All participants								*All participants*							
Intercept	6.98	1.23	**<.001***	[4.48; 9.48]					5.01	0.65	**<.001***	[3.71; 6.31]				
HOB position CL	2.07	0.83	**0.016***	[0.40; 3;75]					-0.75	0.39	0.062	[-1.54; 0.04]				
HOB position N	-0.01	0.81	0.989	[-1.64; 1.62]					-0.91	0.40	0.026	[-1;70; -0.11]				
VSN-	-3.80	1.34	**0.009***	[-6.55; -1.04]					-2.96	0.70	**<0.001***	[-4.38; -1;54]				

CL: contralesional, IL: ipsilesional, SE: Standard Error, SPV: Subjective Postural Vertical, SVV: Subjective Visual Vertical, VSN+: subjects with visuospatial neglect, VSN-: subjects without visuospatial neglect, SRPs are compared with 20° in ipsilesional direction. The head positions are compared with an ipsilesional head position, β: estimate, *$P<.05$

Table 4. Least Squares Means Estimates for HOB position and SRP, accounted for individual

		SVV		SPV	
	HOB position	β (SE)	95% CI	β (SE)	95% CI
VSN-	CL	4.00 (0.62)	[2.74;5.26]	0.60 (0.28)	[0.04;1.16]
	Neutral	-0.18 (0.58)	[-1.36;1.01]	0.69 (0.26)	[0.16;1.21]
	IL	-4.98 (0.62)	[-6.24;-3.72]	-0.45 (0.28)	[-1.02;0.11]
VSN+	CL	11.66 (2.04)	[7.41;15.90]	1.18 (2.53)	[-4.37;6.74]
	Neutral	0.94 (1.85)	[-2.95;4.84]	-1.25 (2.41)	[-6.67;4.16]
	IL	-8.78 (2.04)	[-13.02;-4.54]	-1.27 (2.55)	[-6.85;4.31]

CI: Confidence Interval, CL: contralesional, HOB: Head-On-Body, IL: ipsilesional, SE: Standard Error, SPV: Subjective Postural Vertical, SVV: Subjective Visual Vertical, VSN+: subjects with visuospatial neglect, VSN-: subjects without visuospatial neglect