



Haptic perception of verticality correlates with postural and balance deficits in patients with Parkinson's disease

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ABSTRACT

Introduction: Perception of verticality is fundamental for postural stability that is often impaired in patients with Parkinson's disease (PD). Haptic perception of verticality has not been fully investigated in PD. The aim of the study was to assess subjective haptic vertical (SHV) in PD patients in relation to postural and balance impairments.

Methods: 39 PD patients (mean age 72.87 ± 5.78) and 28 gender and age-matched healthy elderly (ELD, mean age 69.16 ± 13.89) were enrolled. The Pull test and the Activities-specific Balance Confidence (ABC) were used for evaluating balance performance, whereas measurement of posture was performed using the Physical Analyzer System[®]. For evaluating SHV, participants were instructed to provide their subjective vertical by manipulating with two hands a road while standing with their eyes closed.

Results: SHV data showed that PD subjects had a greater deviation from the objective vertical than controls ($p < 0.001$). Significant differences in balance performance (ABC and Pull test) and postural alignment were found between PD and ELD. Only in PD participants, SHV deviations significantly correlated with the lateral inclination of the trunk ($r = 0.618$, $p < 0.001$), pull test ($r = 0.519$; $p = 0.001$) and ABC ($r = 0.471$, $p = 0.002$) scores.

Conclusions: The perception of verticality, driven by multimodal sensory integration, is defective in PD subjects. Deficits in SHV correlated with postural alignment and balance performances, independently from age, disease severity or cognitive decline. Our findings support that PD pathology is associated with a decline in haptic perception suggesting that perception per se might have a causal role in postural and balance deficits.

1. Introduction

Abnormalities of postural control are frequent in Parkinson's disease (PD) and play a prominent role in increasing the risk of falls [1] with severe consequences on independence, social participation and quality of life. A proper functioning of postural control depends on accurate processing of convergent sensory information, such as vestibular, proprioceptive, visual and auditory inputs [2]. The integration of this information builds up the basis of adequate motor responses to environmental challenges. Perception of verticality is fundamental for postural control and can be subjectively assessed by different modalities. Two

common methods have been extensively used: i) the subjective visual vertical (SVV), that relies on visuo-vestibular information, and ii) the subjective haptic vertical (SHV), that depends on graviceptive-somaesthetic information in the absence of visual input. In these tasks, participants are asked to judge the position of a visual or haptic stimulus related to gravity [3,4]. To date, the perception of verticality in PD patients has been investigated by using almost exclusively the SVV. As a whole, results showed that subjective perception of verticality is affected in PD, even in the early stages [5], and associated with postural instability and disease severity (UPDRS and Hoehn and Yahr Scale scores) [6]. In addition, it has been recently demonstrated that axial

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deviations (both in the frontal and sagittal plane) worsened the perception of verticality in PD, when tested by means of SVV [7,8].

Axial kinaesthesia [9] and haptic sensitivity [10] are impaired in PD. Nevertheless, little is known whether deficits in haptic perception do contribute to impaired perception of verticality and are associated with postural instability in PD. The SHV is able to test perception of the verticality depending on multimodal sensory integration (i.e., haptic perception). Indeed, it requires interaction with the environment by grasping, holding and manipulating objects without visual control [11]. Thus, it relies on the integration of proprioceptive, tactile and pressure cues (somatosensory external feedback) in conjunction with the internal representation of the direction of gravity [3,11].

We evaluated the verticality perception by means of SHV in a cohort of patients with PD, in order to determine whether it is associated with postural balance impairments and if this association may be confounded by disease severity, cognitive function, or age. We tested also if worse performances on SHV testing correlated with postural instability (evaluated by the Pull test) and fear of falling (evaluated by the Activities-specific Balance Confidence test).

2. Materials and methods

2.1. Participants

The study involved a total of 67 subjects (recruited at the Department of Neuroscience, University of Genoa), aged between 60 and 85 years, able to walk without any physical assistance, and with Mini-Mental State Examination (MMSE) score > 24. Two age-matched groups of participants were included: 39 consecutive subjects with idiopathic Parkinson's disease (PD, 23 women and 16 men; mean age 72.87 ± 5.78 SD; range: 60–80) and 28 age-matched healthy control (ELD, 16 women and 12 men; mean age 69.16 ± 13.89 SD; range: 56–85). Patients with PD were included according to the following criteria: (i) diagnosis of idiopathic PD (UK Brain Bank criteria [12]), (ii) Hoehn and Yahr stage II–III, and (iii) stable medication since at least 1 month prior to the enrolment. All subjects with a past history of neurological conditions other than PD, or with dyskinesias, severe postural deformities (i.e. Scoliosis, Camptocormia and Pisa Syndrome), peripheral neuropathies and orthopaedic problems of the upper limbs were excluded from the study. Severe postural deformities were identified by taking into account the diagnostic criteria previously published [13]. The study was conducted in agreement with our legal requirements and international regulations (Declaration of Helsinki, 1964). Written informed consent was obtained from all participants before enrolment. All PD patients were under treatment with dopaminergic therapy and clinical and instrumental evaluations took place during the “on” state (≈ 1 h after taking antiparkinsonian medications).

2.2. Clinical assessment

In all participants (ELD and PD), balance performance was assessed by means of the Pull test and the Activities-specific Balance Confidence (ABC) scale. The Pull test evaluates the postural response to sudden body displacement produced by a fast, forceful pull on the shoulders while subject is standing with eyes open and feet apart. It is rated on a score from 0 (Normal: subject is able to recover with one or two steps) to 4 (Severe: subject tends to lose balance spontaneously or with just a gentle pull on the shoulders), according to the Movement Disorders Society (MDS) - Unified Parkinson's Disease Rating Scale (UPDRS) [14]. The ABC scale is a subjective measure of confidence in performing various ambulatory activities without falling or experiencing a sense of unsteadiness. The questionnaire evaluates confidence in performing 16 activities of daily living each activity is rated on a scale range from 0% (not confident) to 100% (fully confident in not losing balance or becoming unstable while performing the activity). General cognitive functions were tested using the Montreal Cognitive Assessment (MoCA)

[15]. MoCA is a brief 30-point test used to assess a broader array of cognitive domains (e.g., attention/executive functioning, visuo-spatial abilities and language). The total maximum score is 30 and a score of 26 and higher is generally considered normal. Furthermore, in patients with PD, disease severity was evaluated with section III of the MDS-UPDRS (Italian version) [14].

2.3. Vertical perception and posture instrumental assessments

Participants' vertical perception was measured with the SHV test. They were instructed to provide their subjective vertical by manipulating with two hands a rod (length = 20 cm, $\varnothing = 1$ cm) while standing on a platform, without shoes and with their eyes closed, in a quiet room. The deviation of the stick from the absolute vertical was expressed in degrees, using positive values for deviation towards the left side of the subjects (anticlockwise) and negative values for deviation towards the participants' right side (clockwise). The absolute values of stick deviation were also calculated to obtain an estimate of the magnitude of SHV independently from the clockwise or anticlockwise deviations. Degrees for the SHV were measured from the angle between the line of gravity of each subject and the line drawn between the two ends of the stick. A schematic representation of SHV test is illustrated in Fig. 1.

Analysis of posture was performed by using the Physical Analyzer System (Global Postural System; Chinesport[®], Udine, IT), an instrumental device used for analysing posture in the frontal and sagittal planes. It consists of a footboard with an aluminium rod along which two webcams slide vertically. Angular deviation of the trunk respect to the vertical axis on the frontal plane was coded negatively when shifted towards the right and positively when shifted towards the left side of the participants. A dedicated software (GPS 5.0 – Chinesport[®], Udine, IT) was used for the acquisition and the analysis of participants' angular deviation of the trunk respect to the vertical axis on the frontal plane and for their vertical perception (SHV). All the analyses were performed off-line based on pictures recorded during the evaluation session. However, the quality of the images (static vs. blurred) were checked immediately so that it was possible to repeat the acquisition if necessary.

2.4. Statistical analysis

Prior the analysis, all variables were examined for normality (Shapiro-Wilk W test) and mean and standard deviation (SD) were calculated. Chi square test was applied for detecting gender difference between groups (PD and ELD). Differences for age and MOCA score were assessed using the non-parametric Mann–Whitney U-tests. SHV (SHV deviations and absolute values of SHV-deviations) and posture data (i.e. trunk angular deviations from the vertical axis and their absolute values) were compared using the Student's t-test. The effect size (ES) for SHV and trunk deviation absolute values was expressed as Cohen's *d* index.

Separately for each group, Pearson's correlation coefficient was used to quantify the relationship between vertical perception (SHV), angular deviation of the trunk respect to the vertical axis on the frontal plane and functional scales (Pull test and ABC scores). Pearson's correlation coefficient was used also, in the PD group, to investigate possible relationships with levodopa equivalent daily dose (LEDD).

Stepwise linear regression models were also built to explain the relationship between SHV and angular deviation of the trunk respect to the vertical axis on the frontal plane and functional scales (Pull test and ABC scores). In three separates models, angular deviation of the trunk respect to the vertical axis on the frontal plane, Pull test score and ABC score were considered as dependent variables and the independent variables were age, UPDRS III and MoCA scores. A standard statistical package computed odds ratios (ORs), two-sided 95% confidence intervals (CIs) and *p* values; *p* < 0.05 was considered to be significant. All statistical analyses were performed using SPSS22.

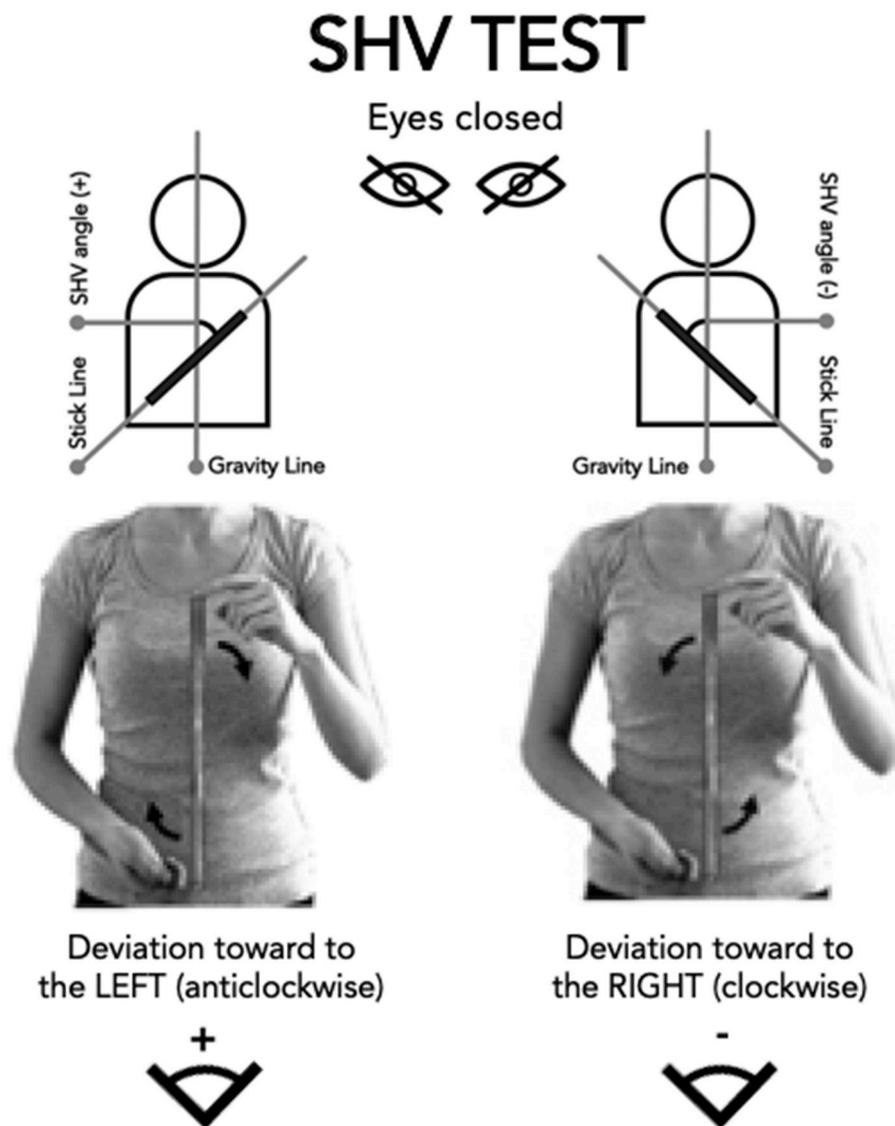


Fig. 1. Subjective haptic vertical (SHV) test. Subjects were asked to provide their subjective vertical by manipulating with two hands a stick, while standing and with their eyes closed. Stick deviation from the absolute vertical was measured in degrees, calculated as the interception between gravity line and stick line. Positive or negative values were assigned based on subjects' side (positive for left, negative for right).

3. Results

Descriptive statistics for demographic, cognitive and clinical (only for PD subjects) data are reported in [Table 1](#). No significant difference for sex, age and education was found between participants enrolled in the two groups.

3.1. Motor and cognitive performance

Results for motor and cognitive evaluations are reported in [Table 1](#). Regarding balance performance, statistical analysis showed a significant difference between groups for data obtained with the Pull test ($p = 0.015$) with a worse performance in PD subjects (mean score = 1.18 ± 1.07 SD) respect to ELD subjects (mean score = 0.61 ± 0.69 SD). The same difference was found also for the ABC scale data. Indeed, PD participants reported having less confidence in performing various ambulatory activities without losing their balance (e.g. walking in a crowded mall or standing on a chair and reach) compared to ELD subjects ($p = 0.019$). As expected, statistical analysis showed that the MOCA score was significantly lower in PD group (mean 25.04 ± 2.37 SD) respect to ELD participants (mean 27.31 ± 1.99 SD) ($p = 0.034$).

3.2. Subjective haptic vertical

Mean value of SHV-deviations was 0.36° in PD group (\pm SD 5.64°) and 0.43° (\pm SD 3.02°) in ELD group. Statistical analysis showed no difference in the mean values between PD patients and healthy controls ($p = 0.95$). Precisely, the SHV was deviated clockwise (towards the participants' right) in 19 PD subjects (48.8%) and anticlockwise in 18 PD subjects (46.1%). In two PD participants (5.1%) the SHV was consistent with the objective vertical (deviation $< 0.5^\circ$). The SHV was deviated towards the right side in 8 ELD subjects (28.6%), whereas in 11 ELD participants (39.3%) SHV was deviated towards the left one. The remaining 9 ELD subjects had a deviation $< 0.5^\circ$, considered as null.

Mean absolute values of SHV-deviations of each group are reported in [Fig. 2A](#). PD patients showed increased absolute inclinations with a mean absolute deviation of 5.13° (\pm SD 2.23°). Data recorded from ELD revealed that the mean absolute deviation was of 2.43° (\pm SD 1.79°). The ES was large (Cohen's $d = 1.11$) and statistical analysis revealed a significant difference between groups in the SHV absolute deviations ($p < 0.001$), showing a greater deviation from the objective vertical in the PD group.

Table 1
Demographics and clinical characteristics of elderly (ELD) and Parkinson's disease (PD) participants.

	ELD group (mean ± SD)	PD group (mean ± SD)	p
Demographics			
Participants (male)	28 (12)	39 (16)	0.56
Age (years)	69.2 ± 13.9	72.8 ± 5.9	0.11
Age range (years)	56–85	60–80	–
Education (years)	11.3 ± 3.8	10.2 ± 4.2	0.69
Clinical data			
ABC (score %)	71.9 ± 19.5	59.9 ± 23.1	0.019*
Pull Test (score)	0.6 ± 0.7	1.2 ± 1.1	0.015*
SHV (°I)	2.4° ± 1.3°	5.1° ± 2.2°	< 0.001*
Trunk Deviation (°I)	2.7° ± 1.9°	5.8° ± 3.6°	< 0.001*
MOCA (score)	27.3 ± 2.0	25.0 ± 2.4	0.034*
MDS-UPDRS Part III (score)	–	34.4 ± 12.0	–
LEDD (mg)	–	655.4 ± 240.3	–

ELD, Elderly; PD, Parkinson's disease; ABC, Activities-specific Balance Confidence, SHV, Subjective Haptic Vertical, °I, degree expressed as absolute value; MOCA, Montreal Cognitive Assessment; MDS-UPDRS, Movement Disorders Society – Unified Parkinson Disease Rating Scale – Motor part; LEDD, Levodopa Equivalent Daily Dose; mg, milligrams.

3.3. Angular deviation of the trunk respect to the vertical axis on the frontal plane

Mean values of angular deviation of the trunk respect to the vertical axis on the frontal plane was -0.31° in PD group (\pm SD 6.87°) and -0.89° (\pm SD 3.19°) in ELD group. Statistical analysis showed no difference in the mean values between PD patients and healthy controls

($p = 0.67$). Trunk inclination was toward right side in 19 PD subjects (48.8%) and toward the left side in 16 (41%); in the remaining four PD participants, the trunk was aligned with the vertical axis. In the ELD group, we found that 13 subjects (46.4%) exhibited a deviation toward the right and 7 subjects (25%) toward the left side. In 8 ELD participants (28.6%) no deviation of the trunk was detected.

The mean absolute value of lateral deviation of the trunk for PD subjects was 5.79° (\pm SD 3.58°) and for ELD participants was 2.68° (\pm SD 1.89°). Statistical analysis revealed a between-groups significant difference ($p = 0.011$) with a large ES (Cohen's $d = 0.93$) with PD participants showing greater inclination of the trunk respect to ELD subjects. Results of absolute values of trunk inclination are depicted in Fig. 2B.

3.4. SHV correlation analysis

Our data revealed a significant correlation between SHV deviations and the lateral inclinations of the trunk in PD subjects ($r = 0.618$, $p < 0.001$; Fig. 2C) whereas no correlation was found in the ELD group ($r = 0.097$, $p = 0.623$). In addition, when a correlation between absolute SHV inclinations and balance performance (Pull test and ABC scores) was explored in the PD group, we found that the greater was the absolute SHV deviation the worse was the postural stability (Pull test score: $r = 0.519$; $p = 0.001$; Fig. 2D) and the less was the confidence in balance activities (ABC score: $r = 0.471$, $p = 0.002$; Fig. 2E). The linear regression analysis showed that all those associations remained significant after having adjusted for age, UPDRS III and MOCA scores (Table 2).

Finally, no significant correlation was observed between LEDD and absolute SHV deviation ($r = 0.126$; $p = 0.443$) or trunk deviation ($r = 0.010$; $p = 0.952$).

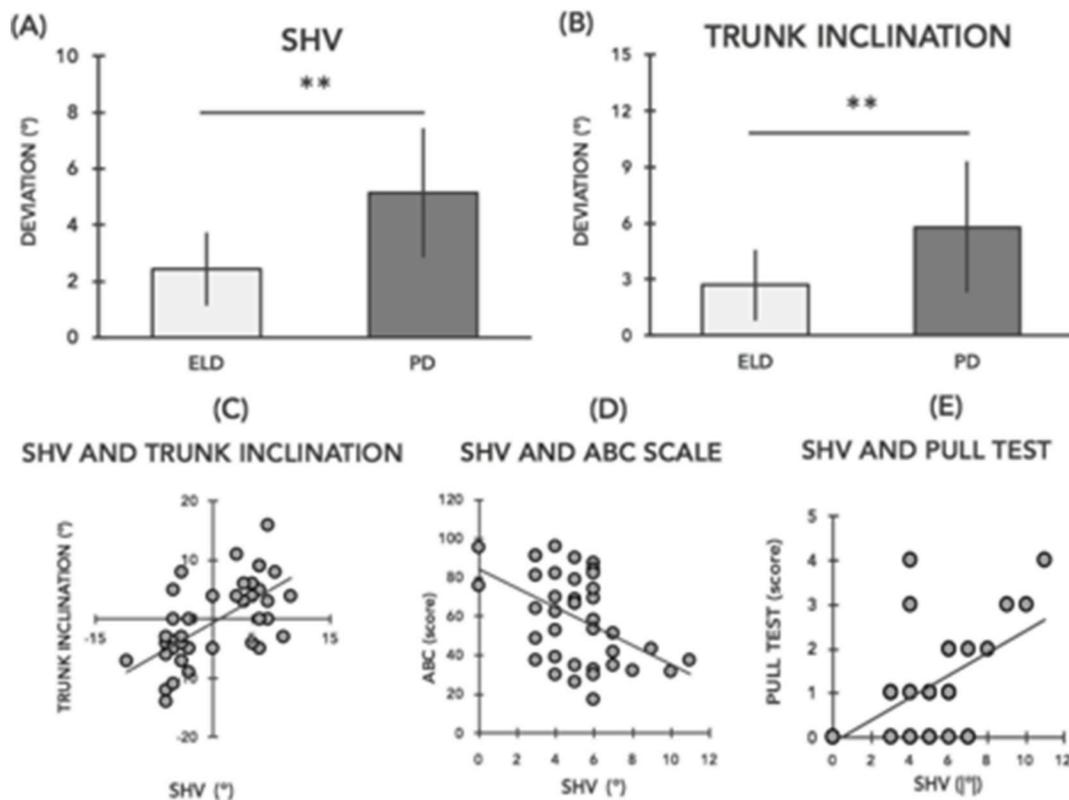


Fig. 2. (A, B, C, D, E). Absolute values of subjective haptic vertical (SHV) deviations are shown in panel (A) and absolute values of lateral inclination of the trunk are reported in panel (B) for elderly (ELD) and Parkinson's disease (PD) groups. Columns represent absolute mean and bars standard deviation values. Asterisks indicate statistical significant difference (** $p < 0.001$). CDE: correlations.

Table 2

Regression model statistics and coefficients of variables for values (°) and absolute values (|°|) of subjective haptic vertical (SHV) deviations in Parkinson's disease (PD) participants.

A. Regression model statistics and coefficients of variables for association between SHV (°) and trunk deviation				
SHV (°)	P	Stand. β	R ²	95% CI
Trunk deviation	< 0.0001	0.62	0.38	[0.29, 0.72]
Adjusted for age	< 0.0001	0.64	0.41	[0.31, 0.74]
Adjusted for age, MDS-UPDRS III	< 0.0001	0.61	0.42	[0.28, 0.72]
Adjusted for age, MDS-UPDRS III, MOCA	< 0.0001	0.58	0.46	[0.26, 0.69]
B. Regression model statistics and coefficients of variables for association between SHV (°) and pull test.				
SHV (°)	P	Stand. β	R ²	95% CI
Pull test	0.001	0.51	0.27	[0.48, 1.67]
Adjusted for age	0.001	0.52	0.27	[0.46, 1.71]
Adjusted for age, MDS-UPDRS III	0.007	0.47	0.28	[0.29, 1.66]
Adjusted for age, MDS-UPDRS III, MOCA	0.005	0.52	0.30	[0.35, 1.81]
C. Regression model statistics and coefficients of variables for association between SHV (°) and ABC test score.				
SHV (°)	P	Stand. β	R ²	95% CI
ABC scale	0.002	-0.47	0.22	[-0.07, -0.017]
Adjusted for age	0.004	-0.48	0.22	[-0.08, -0.016]
Adjusted for age, MDS-UPDRS III	0.017	-0.42	0.25	[-0.07, -0.008]
Adjusted for age, MDS-UPDRS III, MOCA	0.019	-0.42	0.25	[-0.07, -0.007]

SHV, Subjective haptic vertical; MDS-UPDRS III, Movement Disorders Society – Unified Parkinson's disease Rating Scale, Motor part; MOCA, Montreal Cognitive Assessment; ABC, Activities-specific Balance Confidence scale.

4. Discussion

This study demonstrated that haptic perception of verticality is impaired in PD. In addition, a significant correlation was found only in subjects with PD between the absolute deviations in the SHV test and the impairment of postural stability. Finally, our results demonstrated a link between trunk deviation and verticality perception impairment, showing a positive correlation between magnitude and side of deviation in SHV testing and lateral deviation of the trunk. Such correlations were not influenced by age, disease severity or by the global cognitive profile (as screened with the MoCA test).

The majority of studies investigating verticality perception in PD used the subjective visual vertical (SVV) reference, which is built mainly by visual and vestibular afferents [16]. Recent contributions showed that patients with PD had significantly higher SVV deviation than controls [5] particularly when presenting a lateral trunk flexion [7]. These observations are in line with the hypothesis of a peripheral vestibular dysfunction in PD subjects with abnormal posture and an increased risk of falling [17,18]. The latter studies, however, did not investigate whether impaired haptic processing contributes to verticality perception deficits and possibly related clinical features. Indeed, the internal representation of one's body orientation requires integration of visual, vestibular and somesthetic information [2]. Therefore, in the present study we chose to use the SHV, which strongly relies on tactile and kinesthetic inputs, in order to evaluate a pure haptic component related to verticality perception and its possible correlations with abnormalities of postural alignment and stability in PD.

Main results indicate that proprioceptive impairments are likely to coexist with visual dependence and vestibular dysfunction contributing to verticality misjudgements in PD. Correlation between SHV deviations and postural alignment is in line with what reported in the literature related to body tilt and SHV perception. Indeed, a significant SHV deviation towards the body in the case of a “body tilt” condition (i.e., body tilted and head upright) has already been reported [3]. Interestingly, the same authors showed that SHV was unaffected by head tilt alone, but strongly affected by head tilt in the presence of vestibular noise [3]. This result, together with other data in the literature [19,20] suggests that SHV preferentially access a body-based internal model of

gravitational vertical, rather than a head-based one, but also that, when a vestibular cue is present, the body-based and the head-based estimates share information from the relevant sensory inputs [3]. One of the major sensory inputs of the body-based model of gravitational vertical comes from proprioceptive inputs that in SHV testing is integrated with tactile cues (i.e., haptic perception). Thalamo-parietal projections appear to be involved in processing somatic graviception [21,22]. Important evidence supports the notion that proprioceptive deficits are common in PD [23] with impaired kinaesthetic sensitivity to changes in limb position and limb motion [24,25]. Abnormal processing of proprioceptive inputs is likely to occur at a subcortical/cortical level [26–28]. Furthermore, haptic acuity and sensitivity were decreased in PD patients during both active and passive exploration [10], thus suggesting that PD affects the early stages of somatosensory integration, which in turn has an impact on sensorimotor integration. However so far, a direct relationship between decline in proprioception and/or haptic perception and postural deviation and eventually axial deformities has not been systematically assessed.

Another result of the present study is that deficits in SHV testing correlated with balance performance. Our findings might delineate a “specific” sub-phenotype among PD patients who took part in the study. Subjects who showed an impaired haptic vertical perception also experienced issues in the postural instability domain. A link emerged between verticality perception and postural stability or fear of falls, in line with what has been previously suggested [29]. Subjective haptic vertical has been assessed in other neurological conditions such as stroke and a link between SHV, postural control and functionality following stroke has been demonstrated [30]. In this scenario, our findings support the importance of accurate vertical perception for maintenance of postural control, independence in daily living activities and fear of falling.

It will be interesting to follow up over time those patients who participated in this study in order to evaluate their potential deterioration in axial deformities and/or postural instability. This might clarify if SHV testing has a predictive role for higher risk of postural impairments. Although it is difficult to disentangle the different mechanisms contributing to postural abnormalities in PD, since SHV evaluation is a feasible test even in an ambulatory setting it might

become part of the battery of tests performed routinely in evaluating PD patients. Moreover, patients with altered perception of verticality at the SHV test could represent the ideal candidates for an intervention based on proprioceptive rehabilitation [31].

This study has some limitations. First, SHV testing involves a representation of verticality that can be more complex in subjects with cognitive deficits (in particular of spatial imagination). The results were not apparently confounded by subjects' cognitive profile (MoCA), but the lack of a structured neuropsychological battery does not allow to rule out specific cognitive dysfunctions. Second, since a detailed examination of audiometric, vestibular and visual functions was not performed, we cannot exclude their possible contribution to postural abnormalities.

In conclusion, our results confirm that verticality perception is a relevant component of postural control that should be systematically evaluated in patients with PD. If SHV testing would reveal a predictive role for early detection of axial deformities and postural instability it may have an important role in identifying patients at higher risk, and who may benefit from an early start with targeted physiotherapy and/or pharmacotherapy.

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