INTRODUCTION

Postural control in healthy subjects is maintained using vision, vestibular function, and the somatosensory system. Humans use internal reference models to update their sense of verticality, although signs of spatial disorientation are frequent after brain damage. Patients with pushing behavior (PB) after stroke have an atypical balance problem. Perennou et al.1) reported that stroke patients with PB have an altered sense of verticality that is biased to the contralesional side. They designed the wheel paradigm to assess the postural vertical (PV) in the frontal plane (with eyes open and eyes closed) and in the sagittal plane (with eyes closed). Participants were retested 1 week after the first test. The test–retest reliability for each parameter was estimated using the intra-class correlation coefficient [ICC(1,1)], and the minimal detectable change (MDC) scores were established with a confidence level of 95%. Results: The test–retest reliability for the SPV was substantial (ICC ≥0.61). The MDC95 values of the SPVs ranged from 1.1° to 2.1°. Conclusions: The test–retest reliability of the postural vertical in the frontal and sagittal planes was sufficiently high in healthy young participants.

METHODS

Participants

The participants were ten right-handed young healthy adults, five men and five women, with a mean age of 24.0 ± 1.9 years (mean ± standard deviation). The participants met
the following criteria: (1) no orthopedic problems, (2) no visual disorders, (3) no vestibular dysfunction, (4) no psychiatric disorders, and (5) the ability to provide informed consent. All participants received an explanation of the purpose of the study and provided their consent in writing. The study was approved by the ethics committees of Saitama Medical University International Medical Center (12–118).

**Measurement of the Postural Vertical**

The PV was measured using a vertical board that had a semicircular rail attached to the underside. The sides and backs of the participants’ trunks were protected with non-stretchable cloth attached to a metal frame. The participants sat on the vertical board with their feet not in contact with the ground. The participants’ trunks were fixed in a harness, their arms were crossed in front of their chests, and the positions of their heads and legs were not fixed (Fig. 1). This vertical board could be rotated on a semicircular rail up to 90°, and measurements could be obtained in the frontal and sagittal planes (Fig. 2). The vertical board was controlled by two experimenters (A and B). One of the experimenters (A) mainly controlled the movement of the vertical board and the other experimenter (B) supported the board. The experimenters rotated the seat of the vertical board from an

**Fig. 1.** Experimental setup to measure the postural vertical. (A) Experimental setup for measurement in the frontal plane. (B) Experimental setup for measurement in the sagittal plane.

**Fig. 2.** The underside of the vertical board showing the adjustment for measurements in the frontal and sagittal planes. (A) Measurement condition for the frontal plane. (B) Semicircular rail can be rotated through 90°. (C) Measurement condition for the sagittal plane.
initial tilt of 15° or 20° toward a vertical position at a rate of approximately 1.5°/s, which is the threshold for the stimulation of the semicircular vestibular organs. To control the rolling velocity, one well-trained experimenter (A), who was capable of manually ensuring a rolling velocity of less than 1.5°/s, carried out the assessments. The tilt angle of the seat was recorded using a digital inclinometer (Myzox Co., Ltd., Digilevel Compact, Aichi, Japan) in increments of 0.1° when the participants indicated that they perceived themselves to be in an upright position. Eight trials were performed for each parameter in each plane in an ABBABAAB sequence, so that the starting position and angle were in a pseudo-random order. In the frontal plane, A means that the vertical board was initially tilted to the right, and B means that it was tilted to the left. In the sagittal plane, A means that the vertical board was initially tilted forward, and B means that it was tilted backward. The initial tilts for A and B were set at 15° or 20° at random. Trials in the frontal plane were conducted with the participants’ eyes open (SPV-EO) and again with the eyes closed (SPV). In the sagittal plane, measurements were performed with the participants’ eyes closed (SPV). The experimenters monitored whether participants were keeping their eyes closed. To investigate the test–retest reliability, the PVs in each plane were measured twice following the same procedures with an interval of 1 week between the first and second assessments.

**Safety of the Measurement Procedure**

The safety of the PV measurement procedure was evaluated based on the assessment of adverse events, such as nausea or skin irritation. Participants were asked whether they experienced any symptoms, and the condition of the participants’ skin was confirmed by visual examination.

**Data Analysis**

Statistical analyses were performed using PASW Statistics ver. 18.0 (SPSS Japan Inc, Tokyo, Japan), with the level of significance set at 5%. The upright position was considered to be at 0°. Rightward tilts and frontward tilts were considered to be positive, and leftward tilts and backward tilts were considered to be negative. The test–retest reliability for each parameter was estimated using two statistical methods. The intra-class correlation coefficient [ICC(1,1)] was used as a ratio of variances, with ICC ≥0.61 considered to indicate substantial reliability and ICC ≥0.81 considered to indicate almost perfect reliability. The standard error of the mean (SEM) was used to assess consistency in the measurements. The MDC score with a confidence level of 95% was calculated using the SEM based on the following equation:

\[
\text{SEM} = \text{standard error of the difference between the two assessment scores (SDd)} \times \sqrt{2}
\]

\[
\text{MDC}_{95} = \text{SEM} \times 1.96 \times \sqrt{2}
\]

**RESULTS**

At the first assessment, SPV-EO was 1.2 ± 1.0° (mean ± standard deviation) and SPV was 0.9 ± 1.0° in the frontal plane and −0.4 ± 1.1° in the sagittal plane (normal PV range: −2.5° to +2.5°). The ICC, SDd, SEM, and MDC in each plane are shown in table 1. The test–retest reliabilities of SPV-EO and SPV in the frontal plane were substantial, with ICC values of 0.780 and 0.787, respectively. In the sagittal plane, the test–retest reliability of SPV was also substantial, with an ICC of 0.651. MDC values for SPV-EO and SPV in the frontal plane were 1.1° and 1.2°, respectively, and that for SPV in the sagittal plane was 2.1°.

The two experimenters were trained to respond if a participant happened to fall. However, the securing of the participants’ trunks was sufficient, and no adverse events occurred during the course of the study.
This study was the first to establish the test–retest reliability, including the MDC values, of the PV in the frontal and sagittal planes in healthy participants. The ICC and MDC95 values indicated that the PV had a good to fair test–retest reliability in each plane. The ICC values of the frontal and sagittal planes showed the test–retest reliability of the PV measurements. In addition, the SEMs calculated for each plane suggested consistency in the repeated measurements. These findings strengthen the evidence for the test–retest reliability of PV measurements obtained within the same testing session. The primary use of analyses of healthy populations is to allow comparisons with pathological populations, and it follows, therefore, that measurement reliability in healthy populations is of importance. The MDC, which is a statistical parameter, can be used as a threshold to help users distinguish real change from measurement error for an individual participant. The MDC is defined as the smallest value of clinically meaningful change perceived as significant to the participant. In other words, if the value of change between two measurements obtained in separate sessions for an individual participant is greater than the MDC value, it can be concluded that the participant has experienced a real change. Therefore, measuring the MDC is useful when verifying the time course of the tilted perception of verticality (e.g., in patients with PB) and the therapeutic effects of treatment for this disorder. We showed that using a vertical board for the measurement of the PV is technically feasible and that it can safely evaluate the PV in healthy young subjects. This study has limitations. First, only young healthy participants were investigated in this study. Barbieri et al. suggested that participants become less and less accurate in their perception of the PV with increasing age. Second, this study had a relatively small sample size. Thus, further studies should include age-categorized data for the PV and should examine the test–retest reliability with representative samples. In conclusion, the test–retest reliability of the PV in the frontal and the sagittal planes was sufficient in healthy young subjects. We also determined the measurement error of the PV. Therefore, PV measurement using a vertical board is applicable in clinical research.

No financial support was received for this study.

The authors declare no conflicts of interest.