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Original article

Modulating the internal model of verticality by virtual reality and body-weight support walking: A pilot study

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ABSTRACT

Background and objective: The study aimed at inducing a visual vertical (VV) bias by immersion in a virtual tilted room (VTR, visual cues), then testing the effect of 30% body-weight support walking (BWSW, somaesthetic cues) to correct this bias.
Methods: We included 20 healthy participants (median age 54 years; 12 females) who wore the Oculus-Rift® Head Mounted Display to produce the virtual reality and generate the VV. VV (8 trials) was tested at baseline, then in 3 postural conditions (walking, sitting and BWSW), by 2 visual conditions (darkness and VTR), according to a pseudo-randomized blocked design. The VTR was tilted 18° clockwise. Data for 3 participants with virtual reality sickness were discarded, and those for 17 participants underwent non-parametric statistical analysis by 2 main criteria: VV and head orientation.
Results: The VTR induced a pronounced tilt of the vertical toward the tilted side under the baseline condition (median 11.4° [Q1–Q3 6.1–13.4]; $P < 0.01$), with a large effect size ($r = 0.88$). The effect was systematic, with great inter-individual variability (2–17°), and was similar under every postural condition ($P < 0.001$), with a post-effect lasting 6 min and suppressed under BWSW. In darkness, VV was more upright during BWSW than sitting ($P < 0.05$), with a medium effect size ($r = 0.49$). The VTR induced a slight head tilt of median 3.3° [2.8–5.9] toward the tilted side under every postural condition ($P < 0.001$), with a large effect size ($r = 0.87$). In darkness, the head was upright only at baseline and under BWSW.
Conclusion: Being immersed in a tilted environment induces a powerful bias in verticality perception (11°). Contrary to our hypothesis, BWSW did not attenuate the effect induced by the VTR, probably because of the power of this effect. However, BWSW was the only postural condition able to suppress post-effects induced by the VTR, thereby leading to the head and VV oriented upright. BWSW may improve verticality representation, presumably by bringing augmented information about the direction of the Earth vertical. These findings represent an avenue for rehabilitation of patients with postural disorders caused by a wrong verticality representation. Technological improvements will be necessary to attenuate the virtual reality discomfort.

1. Introduction

Internal models serve sensory processing, sensory-motor integration and motor control [1]. They could be a way to construct and update the sense of verticality, by combining vestibular and somatosensory graviception and vision [1,2]. The accuracy of the sense of verticality allows for explicitly perceiving the direction of gravity, building a mental representation of this direction and using the resulting representation to orient the body with respect to gravity. A normal representation of the vertical is required to stand upright and thus walk normally. Some patients with a brain lesion show a bias in the internal model of verticality and consequently align their body with this wrong representation of the vertical, which causes lateropulsion or retropulsion, thereby altering gait. The development of rehabilitation techniques modulating the internal model of verticality is a major challenge for balance and gait disorders related to a misorientation with respect to gravity.

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Manipulating static [3,4] or dynamic [5,6] vision is long known to have a powerful effect on perception of the vertical. As galvanic vestibular [7,8] or somaesthetic stimulations [2,9–13], dynamic visual stimulations [5,6] interact with balance control. Static visual manipulation has the advantage of strongly modulating the internal model of verticality without interfering with postural stabilization [14]. A static tilt of the environment attracts the visual vertical (VV) to the side with maximal effect for a frame tilted 15 to 20° away from the vertical [14,15]. The effect is stronger with cognitive and structural 3D enrichment [15,16] or by immersion in a real tilted environment [4,6,17], which is difficult to implement in a rehabilitation context. New technologies such as virtual reality allow for such complete immersion in a tilted virtual environment, with an effect on perception of the vertical, which remains to be tested.

The first hypothesis of this study was that immersion in a virtual tilted room (VTR) would induce a powerful bias in verticality perception, without preventing the performance of a dynamic task such as walking. Virtual reality is increasingly used in neurosciences, to understand mechanisms [18], quantify spatial deficits [19] and train patients, especially with postural and locomotor task after a stroke [20]. This tool has recently been proposed to assess the VV in static and dynamic conditions [21]. The present study was performed in line with these perspectives.

Post-stroke lateropulsion may be attenuated after body-weight support walking (BWSW) [12]. Our second hypothesis was that BWSW should modulate verticality representation because of the vertical tension yielded by the suspension cable, which gives the brain relevant feedback about the Earth vertical while performing a walking task on a treadmill.

The idea of this pilot study was to experimentally create a VV tilt by using a VTR, then examine how walking suspended or not might affect verticality representation.

2. Methods

2.1. Participants

All 20 healthy participants gave written informed consent and the study was performed in compliance with the Helsinki Declaration. Because of the novelty of the study, the sample size could not be calculated but was targeted at about 15 participants, which is usually sufficient for concluding on verticality perception in experimental studies with healthy controls [9,11] and should be adapted to prepare a further randomized clinical trial in patients. Inclusion criteria were age over 35 years, no neurological or vestibular history, no cognitive or psychiatric disorders and/or gait disturbance. We anticipated that some participants may meet exclusion criterion *a priori* defined as an orientation of the VV beyond usual normal ranges (i.e., ± 2.5° [22]), or might experience virtual reality sickness, so we recruited 20 healthy participants (staff members and relatives) naive to the hypotheses. Their characteristics (presented as median [Q1–Q3]) were age 54 [49–56] years, 12 females; body weight 69 [62–79] kg and height 1.70 [1.65–1.74] m. Their physical activity was classified as high (> 3 h/week, $n = 11$) or low (< 3 h/week, $n = 9$).

2.2. Study design

First, baseline VV was assessed in the sitting position, head and trunk free, after 2 min spent in darkness (head-mounted display [HMD] worn but off) (Fig. 1). VV was successively tested under a dark condition and in the VTR to record reference values for both visual conditions, without any possible interaction with a post-effect induced by a preceding condition/task. Then, VV was tested in 3 postural conditions (walking, sitting and BWSW) according to a pseudo-randomized blocked design (Fig. 1), crossing each postural task with 2 visual conditions (darkness first, then

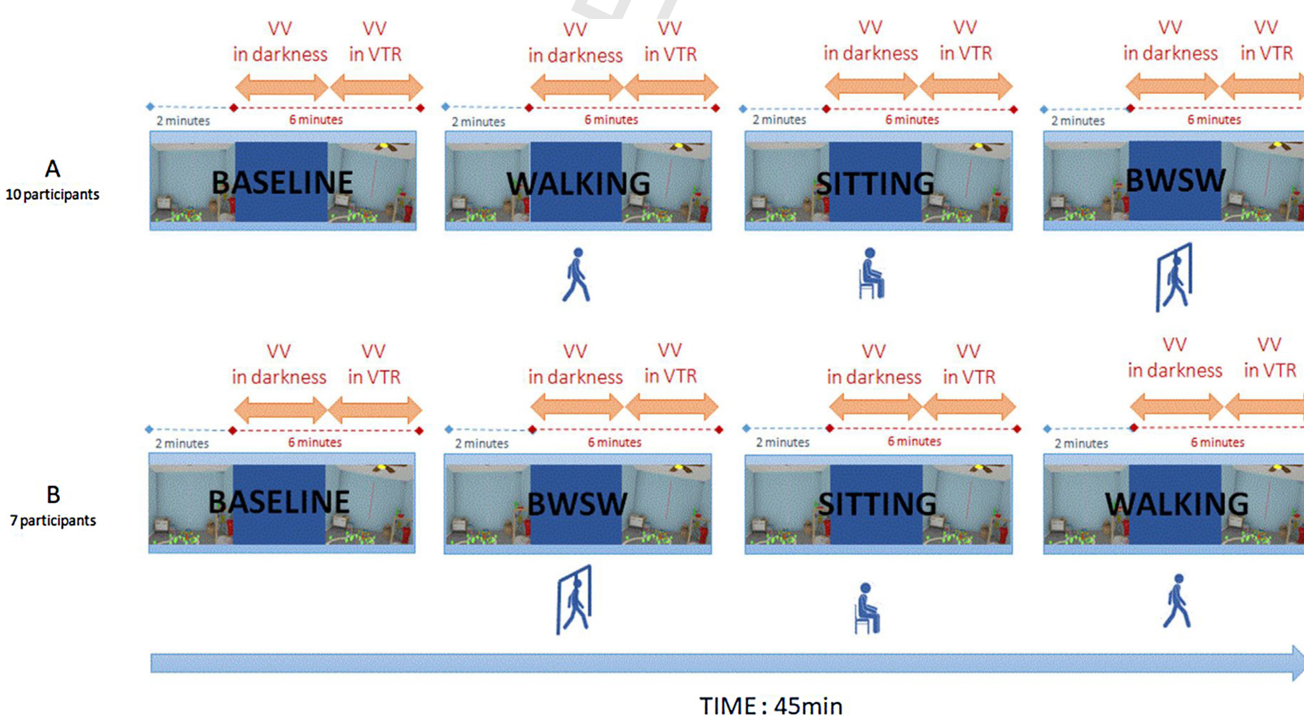

Fig. 1. Protocol diagram, with visual vertical (VV) evaluations in red and postural tasks in blue. Participants were pseudo-randomized in 2 sequences, A or B, with postural tasks performed in reversed orders.

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