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Frequency domain mediolateral balance assessment using a center of pressure tracking task

L. Eduardo Cofré Lizama [a], Mirjam Pijnappels [a], N. Peter Reeves [b], Sabine M.P. Verschueren [c], Jaap H. van Dieën [a,*]

[a] *MOVE Research Institute Amsterdam, VU University Amsterdam, The Netherlands*
[b] *College of Osteopathic Medicine, Michigan State University, USA*
[c] *Musculoskeletal Research Unit, Department of Rehabilitation Sciences, Faculty of Kinesiology and Rehabilitation Sciences, Katholieke Universiteit Leuven, Leuven, Belgium*

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ABSTRACT

Since impaired mediolateral balance can increase fall risk, especially in the elderly, its quantification and training might be a powerful preventive tool. We propose a visual tracking task (VTT) with increasing frequencies (.3–2.0 Hz) and with center of pressure as visual feedback as an assessment method. This mediolateral balance assessment (MELBA) consists of two tasks, tracking a predictable target signal to determine physical capacity and tracking an unpredictable target signal to determine sensorimotor integration limitations. Within and between sessions learning effects and reliability in balance performance descriptors in both tasks were studied in 20 young adults. Balance performance was expressed as the phase-shift (PS) and gain (G) between the target and CoP in the frequency domain and cut-off frequencies at which the performance dropped. Results showed significant differences between the MELBA tasks in PS and G indicating a lower delay and higher accuracy in tracking the predictable target. Significant within and between sessions learning effects for the same measures were found only for the unpredictable task. Reliability of the cut-off frequencies at which PS and G performance declined and the average values within cut-off frequencies was fair to good (ICC .46–.66) for the unpredictable task and fair to excellent for the predictable task (ICC .68–.87). In conclusion, MELBA can reliably quantify balance performance using a predictable VTT. Additionally, the unpredictable tasks can give insight into the visuomotor integration mechanisms controlling balance and highlights MELBA's potential as a training tool.

1. Introduction

Balance impairments are a common cause of falls in the elderly population (Maki et al., 1994; Muir et al., 2010; Salzman, 2010). Detriments of the somatosensory and neuromuscular systems have been identified as causes of imbalance when standing and walking in the elderly (Horak, 2006; Lord et al., 2003, 1999, 2007; Lord and Ward, 1994; Orr, 2010; Orr et al., 2006; Salzman, 2010). The inability to adequately integrate sensory inputs as well as difficulties to perform dual-tasks in which cognition is required have also been identified as causes of balance impairments in older adults (Hay et al., 1996; Maki and McIlroy, 2007; Maki et al., 2001; ShumwayCook et al., 1997). Previous investigations have demonstrated that several biomechanical variables of balance control in the medio-lateral (ML) direction can identify fallers when standing (i.e. ML postural sway measures) and when inducing sideward stepping responses (Brauer et al., 2000; Hilliard et al., 2008; Lord et al., 1999; Maki et al., 1994; Melzer et al., 2010; Williams et al., 1997). There are also indications that center of mass displacement (CoM) in the frontal plane, when compared to sagittal, requires greater active control when walking (Bauby and Kuo, 2000; Donelan et al., 2004; O'Connor and Kuo, 2009). Furthermore, evidence has shown that balance training targeting movements in the frontal plane may reduce the incidence of falls in community-dwelling elderly people (Hatzitaki et al., 2009; Waddell et al., 2009; Yungher et al., 2012).

Despite the discriminative capacity (fallers from non-fallers) of ML balance control reported in retrospective studies, only two of the biomechanical variables (i.e., spontaneous sway of the center of pressure (CoP) during quiet standing and gluteus medius onset time in a stepping response task) have shown poor to moderate accuracy in prospectively predicting falls (Brauer et al., 2000; Maki et al., 1994). It is possible that due to a ceiling effect of current balance assessment tools, including clinical measures, those tests

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[*] Correspondence to: Research Institute MOVE, Faculty of Human Movement Sciences, VU University Amsterdam, van der Boechorststraat 9, NL-1081 BT Amsterdam, The Netherlands. Tel.: +31 20 5988501; fax: +31 20 5988529.
E-mail address: j.vandieen@fbw.vu.nl (J.H. van Dieën).

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are not sensitive enough to detect balance impairments and predict falls in high functioning elderly and in able-bodied subjects (Bhatt et al., 2011; Brauer et al., 2000; Faber et al., 2006; Muir et al., 2010; Pardasaney et al., 2012). Therefore, a more sensitive assessment method should challenge balance more to avoid ceiling effects and yet be simple enough to be applied in a clinical environment (Pardasaney et al., 2012; Woollacott, 2000). In this context, we propose a medio-lateral balance assessment (MELBA) method, which uses a visual tracking task (VTT) and the ML CoP displacement as feedback on performance.

In the VTT subjects have to elicit voluntary ML CoP movements based on visual information of the target and subordinating proprioceptive and vestibular sub-systems to maintain stability. By increasing task difficulty (i.e. increasing target frequencies), the subject is challenged to respond fast and accurately. These aspects of the response are necessary when coping with perturbations in daily life situations and reflect the integrity and compensatory ability of the balance system. MELBA aims to quantify balance performance using a visual tracking task, whereby balance control is then characterized by gain and phase-shift between target and CoP signals. MELBA consists of a predictable target, which allows feed-forward mechanisms to control balance in order to determine maximal physical capacities, and a second, unpredictable target, which increases the demand of feedback mechanisms in order to quantify limitations in sensory integration.

This study aimed to determine the methodological properties of MELBA by assessing learning effects within and between sessions as well as reliability of the performance, i.e. the consistency of the method when no interventions are made. Additionally, balance performance between the two MELBA tasks (i.e., predictable versus unpredictable) was compared.

2. Methods

2.1. Subjects

Twenty healthy young adults, 12 women and 8 men, participated in this study (age: 28 ± 3 years; height: 1.75 ± .1 m; weight: 70 ± 8 kg). Participants did not report any musculoskeletal or neurological condition that may have affected balance. This research was approved by the local Ethical Committee, in accordance with the ethical standards of the declaration of Helsinki. All subjects were informed of the experimental procedures and signed an informed consent form prior to the experiment.

2.2. Task and procedure

Each participant performed a series of visual tracking tasks (VTT) while standing barefoot and with the arms crossed on a force-plate located in a quiet and low-intensity light room (for set-up details see Fig. 1). CoP data were obtained using a Kistler-9281B force plate (Kistler Instruments AG, Winterthur, Switzerland) sampling at 60 samples/s. D-flow 3.10.0 software (Motek Medical, The Netherlands) was used to produce target signals as well as to record and display target and CoP data on the screen. The delay of the system was calculated to be 16 ms which is equivalent to 1 sample.

A *predictable* target signal was constructed using 18 blocks of 5 s, each composed by one sine wave, which increased from .3 to 2.0 Hz in steps of .1 Hz. This information was enhanced using a metronome synchronized with the maximum displacement of the target in order to increase sensory input abundance. The total task time was 90 s.

An *unpredictable* target signal was constructed using 15 blocks composed by the sum of 6 consecutive sine waves separated by .1 Hz. A pseudorandom phase-shift between sine waves between −1 and 1 periods was introduced in order to avoid predictability. After each block the lowest frequency, which started at .1 Hz was increased by .1 Hz higher until it reached 1.5 Hz. Duration was 10 s for blocks 1 and 2, 8 s for blocks 3 to 7, 6 s for blocks 8 to 11 and 4 s for blocks 12 to 15. Duration of the blocks was chosen in order to obtain at minimum of 2 cycles per frequency contained in the block. This target construction also allowed limiting the total task time to 100 s. The unpredictable target bandwidth started at a lower frequency than the predictable target, but results in the frequency range .1–.2 Hz were not analyzed. An example of the two target signals is depicted in Fig. 1.

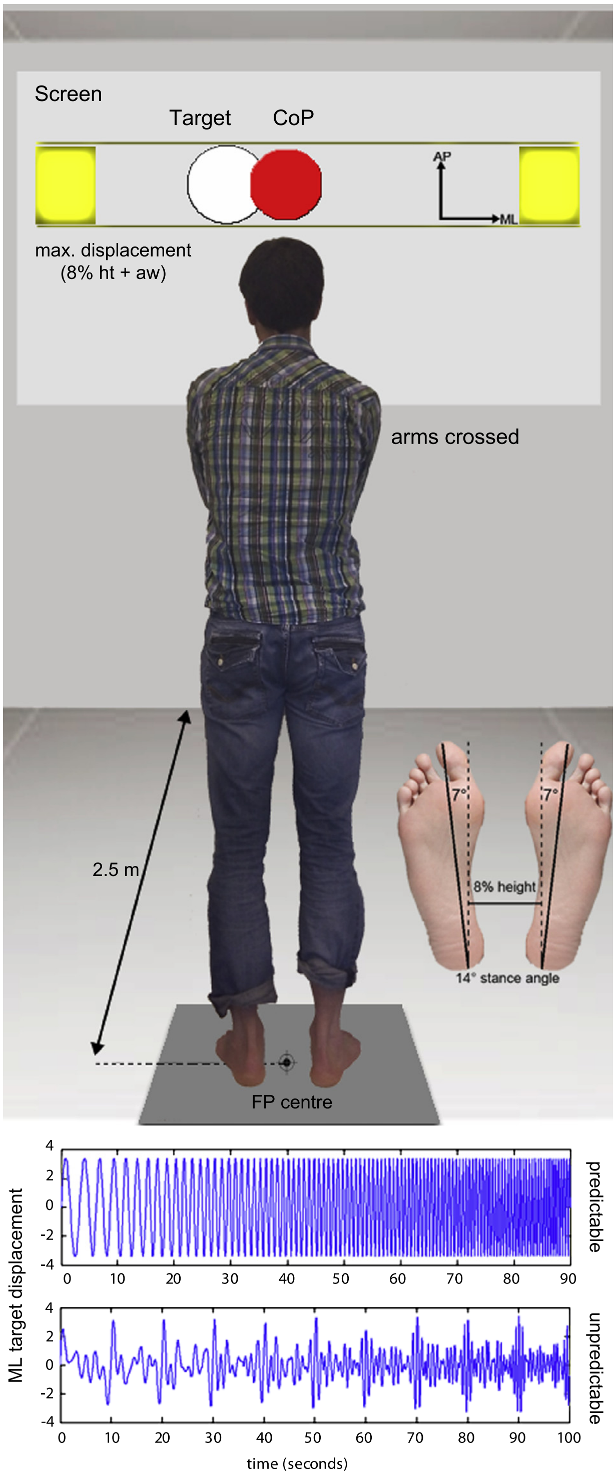

Fig. 1. Illustration of the experimental set-up from a rear view. The CoP (center of pressure) is represented as red sphere, whereas a white sphere represents the target signal, on a display located 2.5 m in front of the forceplate (FP). The height (ht) and ankle width (aw) were used to determine the maximum amplitude of the target indicated by the yellow areas projected at both sides of a corridor delimited by a top and bottom horizontal bars. These bars indicate the tolerance for anterior–posterior (AP) displacement which was set at 2 cm. Additional auditory feedback ("beep") was given when these AP boundaries were exceeded. The figure of feel soles inserted at the right depicts foot positioning across all trials (7° rotation of each foot with an intermalleoli distance equal to 8% of ht). The lower panel depicts the predictable (top) and unpredictable (bottom) targets. Negative and positive values indicate left and right CoP displacements, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)