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Virtual reality balance training for elderly: Similar skiing games elicit different challenges in balance training

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ABSTRACT

Background: Virtual Reality (VR) balance training may have advantages over regular exercise training in older adults. However, results so far are conflicting potentially due to the lack of challenge imposed by the movements in those games. Therefore, the aim of this study was to assess to which extent two similar skiing games challenge balance, as reflected in center of mass (COM) movements relative to their Functional Limits of Stability (FLOS).
Methods: Thirty young and elderly participants performed two skiing games, one on the Wii Balance board (Wiiski), which uses a force plate, and one with the Kinect sensor (Kinski), which performs motion tracking. During gameplay, kinematics were captured using seven opto-electronical cameras. FLOS were obtained for eight directions. The influence of games and trials on COM displacement in each of the eight directions, and maximal COM speed, were tested with Generalized Estimated Equations.
Results: In all directions with anterior and medio-lateral, but not with a posterior component, subjects showed significantly larger maximal %FLOS displacements during the Kinski game than during the Wiiski game. Furthermore, maximal COM displacement, and COM speed in Kinski remained similar or increased over trials, whereas for Wiiski it decreased.
Conclusions: Our results show the importance of assessing the movement challenge in games used for balance training. Similar games impose different challenges, with the control sensors and their gain settings playing an important role. Furthermore, adaptations led to a decrease in challenge in Wiiski, which might limit the effectiveness of the game as a balance-training tool.

1. Introduction

Independence at older age is greatly compromised by fall-related injuries. About 40% of those aged 65+ fall at least once per year. About 10-20% of these falls result in hospitalization. The high incidence of falls is attributable to risk factors such as age-related decreases in postural control and strength [1,2]. However, balance training programs can improve postural control and muscle strength and thereby reduce the risk of falls [3–5].

Unfortunately, training effects disappear when training programs are stopped, which indicates a need for on-going training [6–8]. Home based training programs, however, often have poor adherence due to a lack of motivation [9,10]. Virtual Reality (VR) training applications might improve motivation, by introducing a game element. Furthermore, the ability of the VR training to adapt and progress according to the skill level of the player, ensures the appropriate challenge, therefore conforming to the recommendation to prescribe training for elderly relative to their own capabilities [11].

Despite the advantages of VR training, systematic reviews studying the effectiveness of VR balance training for elderly yielded conflicting results [12–14]. This could be partially attributed to the heterogeneity of the included studies and differences in experimental designs, e.g. comparison of VR training to traditional training or a control group, as well as to the free interpretation of the term VR training. Indeed, VR training encompasses a wide variety of computer-assisted training forms, ranging from off-the-shelf toy games with different controllers, such as the Wii Balance Board, Xbox Kinect and Playstation Eyetoy, to applications specifically designed to be controlled by scientific-grade equipment. The extent to which different types of VR training challenge balance remains unclear.

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Strict guidelines regarding the intensity of balance training are lacking, because intensity is hard to quantify in this context. Moreover, the large variation in movement capabilities and fitness levels in the elderly population, requires intensity to be prescribed relative to an individual's fitness level [11]. Several reviews on the effectiveness of programs to reduce fall risk have proposed general recommendations [6,8,15]. Balance training for elderly has to include strength and balance specific exercises [1,6,15]. More specifically, balance programs should involve a moderate or high challenge to balance, by reducing the Base Of Support (BOS) and introducing weight shifts [6,11,16–18]. Furthermore, the intensity should increase as the individual progresses [6,11].

Medio-lateral (M-L) weight shifting performance has been linked to aging, balance and falls [19,20]. Ski slalom is a sports activity that mainly involves M-L movements, so a VR skiing game has the potential to induce challenging M-L weight shifts towards the limits of stability.

1.1. Aim

The aim of this study was to compare the weight shifts in two similar skiing games using different controllers, currently being used for VR balance training. To this end, we compared Center Of Mass (COM) displacements, expressed as a percentage of participants' functional limits of stability (%FLOS). The game and controller that encouraged players to move more towards their limits of stability, and move faster, was considered most challenging. In addition, we analyzed the trial effect to assess whether the challenge changed after familiarization, and we analyzed whether more movement of the COM in fact led to higher scores to confirm that the game element is an inherently positive stimulus.

2. Methods

2.1. Participants

In this experimental study, we recruited thirty young adults and thirty healthy older adults. All participants volunteered to participate after flyers were distributed around the sports facilities of KULeuven University. The age range for young adults was 18 to 35. Older adults were aged > 65 years and were community dwelling. All subjects were healthy, meaning that they could stand for at least twenty minutes, had a Mini-Mental state score > 25, did not have severe pathology of the musculoskeletal, neurological or vestibular system, severe cardiovascular disease, diabetes, nor did they use beta-blockers or antidepressants. Subjects signed a written informed consent prior to participation, in accordance with the Declaration of Helsinki. The study was approved by the local ethics committee (Commissie Medische Ethiek K.U. Leuven).

2.2. Materials

Two games were tested: Kinski was played on the Xbox (Microsoft, Redmond, WA, US), using the Xbox Kinect camera to track the player's movements, via depth sensing cameras. The Wiiski game was played using the Wii and its accompanying Balance Board (Nintendo, Kyoto, Japan) registering movements of the Center of Pressure (COP). The objective in both games was to steer an avatar skiing down a slalom track. The time taken to complete the track, plus penalty time for missed gates determined the game score. Participants could change speed by leaning forward or backward, and move from left to right by shifting their weight accordingly. The virtual environment was projected on the same projection screen for all games and tests.

During game play, 3D-kinematics were captured using seven MX-T20 opto-electronical cameras (Vicon, Oxford Metrics, UK) at 100 Hz. Full body COM was calculated in Matlab (MathWorks, New Mexico) based on a 45-markers, 15-segments full-body linked segment model [21], such that each segment was tracked by at least three markers.

To obtain personalized limits of stability, a dedicated FLOS test was designed to obtain the maximal distance that each subject could move their COM in eight different directions, away from the self-selected upright position, moving as much as possible as a rigid body, without bending the knees, hips or lower back, and without taking a step. The directions specified were anterior-right, right, posterior-right, posterior, posterior-left, left, anterior-left and anterior. COM position was estimated, from 18 markers forming 10 segments that were scaled to participants' anthropometric data and gender [22], and direct feedback was provided on screen during the FLOS task. In post processing, the COM was recalculated based on full body kinematics to determine the functional limit in each direction based on the maximum value of the three trials. The COM displacements obtained during incidental stepping and when lifting the heels were discarded.

An example of the COM trajectory during game play with respect to the participant's FLOS is given in Fig. 1. To quantify the subject specific challenge, the maximum displacement of the COM from the center was calculated and normalised to the displacement during FLOS for each direction. To evaluate the association between the movement of the COM and the game score, the area of the 95% confidence ellipse fitted around the COM trajectory was calculated and the scores were categorized as belonging to the top, middle or lowest tertile. Besides COM displacement, speed affects the extent to which balance is challenged [23]; therefore, we also analyzed peak COM speed.

2.3. Protocol

Participants were screened for exclusion criteria and anthropometric data were obtained. For elderly participants, we administered the Mini Mental State Exam (MMSE). Following the preparations, participants performed the FLOS task three times and played the games in a randomized order, obtained from a computer-based random number generator [24]. Stance width was standardized during the FLOS tasks and both games by markers on the floor and on the Wii balance board. After each game, participants were asked to sit down and take a rest.

2.4. Statistics

A Generalized Estimated Equation (GEE) was used to test whether game, age, group, trial and their interaction effects could explain differences in COM displacements. The GEE was chosen to accommodate data not meeting the assumptions of equal variances and to deal with missing data, for example due to enthusiastic participants who did not succeed to play the game without changing their BOS. Additionally, a GEE was used to test whether the area of the 95% confidence ellipse around the COM trajectory, could predict whether the game score would be in the top, middle or lowest tertile. Finally, a GEE was performed to analyze the effect of the games, group and trials on the peak COM speed. Post-hoc pairwise comparisons were done using Least Significant Difference (LSD). Level of significance was set at $\alpha = 0.05$. The statistics were performed in IBM SPSS Statistics Version 21.0.

3. Results

The characteristics of the participants are summarized in Table 1. GEEs on COM displacement showed that for all directions without a posterior component, a main effect of game was found. The displacements of the COM were significantly larger in all these directions for the Kinski game compared to the Wiiski game (Fig. 1). A summary of all model effects is given in Table 2. Furthermore, maximum COM speed was significantly higher in Kinski compared to Wiiski (0.54 m/s ± .03 compared to 0.28 m/s ± 0.01; $p < .001$).