KATHOLIEKE UNIVERSITEIT LEUVEN

GROEP BIOMEDISCHE WETENSCHAPPEN

FACULTEIT BEWEGINGS- EN REVALIDATIEWETENSCHAPPEN

The use of exergames to improve balance in elderly: Can we challenge COM displacements?

Bijdrage tot het project: Erasmus Mundus 'Move Age'

door Julie TAVERNIER
en Jente WILLAERT

masterproef aangeboden tot het behalen van de graad van Master of Science in de lichamelijke opvoeding en de bewegingswetenschappen

o.l.v.
Prof. dr. S. Verschueren, promotor
A. de Vries, copromotor

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Opgesteld volgens de richtlijnen van *Gait and posture*

WOORD VOORAF

We schreven deze masterproef in het kader van onze masteropleiding Lichamelijke Opvoeding en Bewegingswetenschappen aan de Katholieke Universiteit in Leuven. Via deze weg willen we iedereen bedanken voor de steun tijdens het volledige proces van deze masterproef.

In de eerste plaats willen we Prof. dr. Sabine Verschueren bedanken voor de ondersteuning tijdens deze masterproef en het talloze keren nalezen van de tekst. Daarnaast willen we graag onze copromotor Aijse de Vries bedanken voor de nauwe samenwerking om dit project tot een goed einde te brengen. Verder willen we jullie ook bedanken voor de kans die jullie ons gaven om tijdens dit proces toch op buitenlandse stage te kunnen gaan. Jullie geduld, bijsturing en hulp tijdens deze niet zo alledaagse manier van werken betekenden veel voor ons.

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Bedankt aan iedereen om ons door deze intensieve, maar uiterst boeiende en leerrijke periode te loodsen.

Waregem, 6 mei 2018 J.T.
Kapellen, 6 mei 2018 J.W.

SITUERING

Deze masterproef kwam tot stand als onderdeel van een PhD binnen het Erasmus Mundus ‘Move Age’ project (www.move-age.eu). In dit project kregen ongeveer 50 PhD studenten een beurs voor een doctoraatsonderzoek naar hoe men mensen mobiel kan houden wanneer ze ouder worden. Het ‘Move Age’ project is een samenwerking tussen 3 verschillende Europese universiteiten namelijk Vrije Universiteit Amsterdam, Manchester Metropolitan University en K.U. Leuven. Deze masterproef valt binnen de onderzoeksgroep Musculoskeletale Revalidatie van de faculteit Bewegings- en Revalidatiewetenschappen aan de KU Leuven. Het doel van deze masterproef was om na te gaan of een zelf ontwikkeld virtual reality (VR) spel, dat gebruik maakt van de individueel bepaalde functionele limieten van balans (functional limits of stability, FLOS), uitdagender is op het vlak van evenwicht dan andere commerciële VR spellen.

Het deel van de wereldbevolking ouder dan 60 jaar neemt toe en zal nog blijven stijgen in de komende jaren.[1] Ouderdom zorgt voor functionele en biologische veranderingen die het risico op vallen aanzienlijk verhogen. Er wordt geschat dat tenminste 30% van de senioren elk jaar valt.[2] De gevolgen hiervan brengen grote kosten met zich mee voor de sociale gezondheidszorg. Daarom is onderzoek naar valpreventie bij ouderen cruciaal.[2,3]

Verschillende trainingsprogramma’s, met als doel de risicofactoren voor vallen te verminderen, zijn al ontwikkeld en onderzocht op effectiviteit. Klassieke kracht- en evenwichtstraining is de meest voorkomende vorm van valpreventie. Het is aangetoond dat deze programma’s kunnen bijdragen tot een verbetering in controle van houding en evenwicht bij ouderen.[2] Andere vormen van valpreventie zijn Tai-Chi en Whole Body Vibration (WBV) trainingen.[4,5] Uit recent literatuuronderzoek blijkt dat het uitdagen van evenwicht, door het verplaatsen van het center of mass (COM), nodig is om het risico op vallen te verminderen.[6] Hoewel verschillende programma’s een positief effect aantoonden, kon dit resultaat slechts bereikt worden na het voldoende lang volgen van de training. Dit is echter een van de grote struikelblokken bij evenwichtstraining wat weerspiegeld wordt in grote drop-out cijfers. Een van de voornaamste redenen hiervoor is dat de oefeningen als eentonig en onnuttig beschouwd worden.[7] Meer recent is er aangetoond dat VR spellen zorgen voor een verhoogde intrinsieke motivatie, wat de hoge drop-out cijfers zou kunnen tegengaan.[8] Deze nieuwe vorm van techniek kent een opmars in de ontwikkeling van valpreventie programma’s.

VR is een computer gesimuleerde omgeving die gebruikt kan worden voor evenwicht trainingsprogramma’s. Verschillende spellen zoals het Wii fit spel, dansspellen en Kinect adventure zijn reeds ontwikkeld en zorgden op zijn minst voor een lichte verbetering in evenwicht.[9] Voor het verbeteren van evenwicht tijdens dagelijkse taken bij ouderen zijn uitdagingen in het verplaatsen van de COM nodig. Uit voorgaand onderzoek van de Vries et al. is er aangetoond dat op basis van kinematica aangestuurde exergames op dit vlak beter scoren dan exergames die gestuurd worden via center of pressure (COP) verplaatsingen. Desondanks vertoonden deze spellen geen grote uitdaging op het vlak van COM verplaatsingen.[10] Dit gaf aanleiding tot het ontwikkelen van een nieuw spel, VirBal, gebaseerd op de individuele functionele limieten van evenwicht, wat voor een grotere uitdaging van COM verplaatsingen zou moeten zorgen.

Het doel van deze studie is om na te gaan wat de COM verplaatsingen zijn tijdens het VirBal spel en of deze groter zijn dan het Kinect Ski, referentie spel. Dit bleek uit voorgaand onderzoek grotere COM verplaatsingen uit te lokken in vergelijking met andere commerciële spellen die momenteel op de markt zijn. Tot slot zullen we ook een vragenlijst gebruiken om na te gaan hoe gemotiveerd de deelnemers zijn tijdens het spelen van het spel.

Indien na dit onderzoek blijkt dat het spel uitdagend is in termen van COM verplaatsingen en het voldoende intrinsieke motivatie creëert bij de deelnemers, zou het spel gebruikt kunnen worden in een toekomstige interventie studie voor valpreventie bij ouderen.

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Bijdrage tot het project: Erasmus Mundus 'Move Age'

Abstract

Background

The occurrence of falls in elderly is a problem for the community and appears to be difficult to treat due to high dropout rates in classic fall prevention programs. Recently, more interest is shown in exergames to train elderly, since it can increase intrinsic motivation and train balance by center of mass (COM) displacements, a key component in balance training. However, these games appear to challenge balance not sufficiently and improvements in movement demands in games appear necessary to improve the effectiveness for balance training.

Research question

This study investigates if the custom made VirBal game challenges balance, measured by COM displacements expressed relative to the individuals' functional limits of stability (FLOS), more than the Kinect Ski game, that showed to be most effective in inducing weight shifts when comparing different off-the-shelf games.

Methods

Sixteen healthy elderly from the neighborhood of Leuven (Belgium) were tested in the Movement and Analysis Laboratory Leuven. Individual FLOS values were determined by using the FLOS test and used as individual settings to play the VirBal game. Displacements of COM were measured using 3D-motion analysis and compared between the VirBal and Kinect Ski game. Generalized estimate equations were used to determine any difference in COM displacements between games. If significant differences were found, post-hoc pairwise comparisons were done, using Bonferroni adjustments.

Results

The VirBal game showed higher COM displacements in all eight directions compared to the other tested games. For the left direction, also a significant game*trial interaction effect was seen, indicating a steep increase in COM displacements for the Slingshot game as trials progress.

Significance

Given the positive results of the VirBal game, it might be promising to do an intervention study in elderly to test effectiveness and adherence in balance training programs and whether it could contribute in the prevention of falls.

Introduction

The worldwide population aged above 60 years is increasing and will further increase in the next years. In 2015, 12% of the worldwide population was aged above 60 and this is predicted to further increase to 16.5% by 2030. Looking at Europe, even higher percentages were observed with an increase to 30% by 2030.[1] This contributes to higher demands on the public and social healthcare.[2]

Almost 30% of the seniors living on their own and 50% of seniors living in a nursing home fall every year. This amount increases with age, functional disability and impairment.[3] Aging causes several biological changes that influence our functional capacities and accordingly the risk factors for falling. Elderly experience a reduction in eyesight, reactions are slowing down and walking and keeping balance becomes more difficult.[4,5] Furthermore, sarcopenia, which is a loss of skeletal muscle mass and a decrease in muscle strength, is also related to biological aging.[5] In this respect, the fast contracting type II muscles, which are needed to prevent a fall, decrease more in elderly than type I muscles, which are important for standing balance.[5] Falling is a major threat to daily functionality in elderly and can cause long standing pain, disability and even death.[3,6] Although this does not occur in all cases, sometimes medication or a hospital stay is needed. Additionally, social isolation, less confidence and fear of falling could be long lasting effects.[3,6] Based on this huge impact of falls, both for the individual and society, research on structured balance training programs, aiming at preventing falls in elderly, is crucial.

Balance and strength training programs have been developed in an attempt to decrease the risks associated with falling.[3] Improvement of postural control in healthy elderly was obtained after fitness training three times a week for one year, focusing on cardiovascular, strength, balance and stretching exercises.[7] Improvement in functional balance after Tai-Chi training is associated with a reduction in falls in older adults after 6 months of training.[8] According to Kannus et al. balance training including strength and flexibility exercises leads to a decrease in 15 to 50% in the occurrence of falls.[3,6] More recently, perturbation training, whereby conditions, that match real life situations where balance recovery is needed are created, showed greater effects in preventing falls compared to classic balance training. The main factor for these results comes from the learned ability to adjust the center of mass (COM) as a reaction on a perturbation, which plays a critical role in preventing falls.[9]

Sherrington et al. reviewed the available studies and listed several recommendations for such training programs to be effective. The content of the training has to be challenging for balance for example by inducing movements of the COM to the limits of stability, by reducing the base of support (BOS) or by prohibiting the use of the arms for support. A decrease in available sensory input, either vision or proprioception, and adding a cognitive task could also lead to more challenging exercises.[7,8] More recently, Granacher et al. recommended to add reactive components to these single-task static and dynamic exercises.[12] Another type of exercise program recommended for elderly people to prevent falls is Tai-Chi.[3,10,11,12]

Besides the physical aspects of proper balance training, also adherence to the training program is crucial. A high dose of continued balance training is prescribed in literature to improve functional balance in healthy elderly.[10,14] Thus, an important factor to consider for improving adherence to a training program is intrinsic motivation. People will follow a training program more strictly and during a longer period of time if they consider these activities useful for themselves.[15] Unfortunately, adherence to home training programs is low, possibly due to insufficient support, amount of exercises, monotonous exercises and problems with perceived usefulness. The lowest dropout rates are found by programs with balance or walking exercises, combined with moderate home visit support and supervision by physiotherapist during exercises.[16]

During the last 5 years, more interest is shown in the use of virtual reality (VR) in training programs, whereby a person is emerged in a computer simulated environment. This type of training is sometimes also referred to as exergames. Using a VR training program might have some advantages over normal training. The difficulty of the game can be adjusted to the performance level of the participant and progression can be made during a training period. Further, VR has been introduced as a mean to improve adherence to a program by increasing the fun aspect while practicing balance. Fitzgerald et al. showed a higher level of interest and fun in a group of participants doing traditional balance exercises while playing exergames compared to a control group, only doing traditional exercises.[17] The fact that VR provides entertainment and because personal and immediate feedback on performance can be provided, VR training is thought to have positive effects on training adherence and might thus be an interesting approach to reduce dropout numbers of training.[18,19,20] Several studies have assessed the use of exergames in healthy elderly to improve balance and functional mobility, however, with conflicting results possibly due to the wide variety of exergames that are being implemented as training programs in those VR studies.[21,22,23,24] A lot of research is done with the Wii fit game and accompanying balance board, where a virtual representation is moved by displacements of the center of pressure (COP). Also dance games have been studied recently, but none of these studies have led to conclusive results, possibly due to heterogeneity between studies and differences in experimental designs.[25] Training using exergames showed at least minimal improvement in balance, when measured by clinical and instrumented outcome measures.[21,22,26] However, training in these games was not adjusted to individual margins of balance. This led to a difference in challenge to balance between individuals, which could have given biased results. Finally, the main reason for the development of these games was not to provide a balance training program, but to entertain the players. They did not aim for the balance recommendations and currently there are no existing studies to examine if the performed movements during the games are appropriate to train balance.

Based on above mentioned recommendations for effective balance training, games with greater COM displacements and changes in the BOS are needed to stimulate balance control.[27] However, the actual movements performed during the games were only tested in one previous article so far. In this experiment, performed in our laboratory, de Vries et al. tested the COM displacements in two different skiing games and showed a significant higher challenge in balance in games controlled by kinematic measurements (Kinect) compared to other off-the-shelf games, using COP displacements to play the game (WII fit).[28] Improvements in challenge of balance can thus still be made in games. Beside balance, also strength must be considered in developing a balance training program.[29] De Vries et al. also assessed the muscle activation during performance of nine different existing games and found only low muscle activation, < 40% maximal voluntary contraction (MVC), in off-the-shelf games like Wii balance games as well as a lack of periods of prolonged activation.[20]

The previous studies performed in our laboratory with respect to the challenge to balance and muscle activation in off-the-shelf games showed that these games leave ample room for improvements.[28] To induce more changes in COM displacements and therefore leading to more challenges of balance, a new custom-made game, VirBal, a combination of four mini games, has been developed. VirBal aims to combine essential components of a fall prevention training program for elderly and offering a motivating training experience to assure a high rate of adherence. In the games the COM displacements are based on the individual functional limits of stability (FLOS) levels, as assessed with a custom made FLOS test. This assures that every participant can play the game at his own performance level and that the games are of similar difficulty for everyone.

This study will investigate whether Virbal succeeds in optimising the challenge to balance in all directions compared to a Kinect Ski game as a reference, which was shown to be most effective in inducing challenging weight shifts in a previous study.[28] Furthermore, intrinsic motivation for playing each game was assessed using the Intrinsic Motivation Inventory (IMI) questionnaire. If the results show that VirBal displays challenging COM displacements and high intrinsic motivation, this game could be tested in a balance training study in a population of elderly and might be promising to improve effectiveness and adherence in balance training programs.

Methods

Participants

A total of sixteen healthy, older adults were recruited from the neighbourhood of Leuven (Belgium) at sport facilities and social activities for elderly. The selection criteria were aged between 65 and 80 years, free of musculoskeletal, neurological and vestibular problems and able to stand longer than 20 minutes. Of the 16 participants, 7 were males (mean age: 67,29 years) and 9 of them were females (mean age: 70,11 years). To ensure all subjects were in a cognitive good state, the Mini Mental State Examination (MMSE) test was performed. Participants had to score at least 25 out of 30 to be eligible for the study. Mean score of the participants was 29 out of 30. Subject characteristics are shown in table 1.

Table 1: Subject characteristics

	Mean	**SD**
Number	16	
Sex	9f / 7m	
Age	68,93	2,68
Length (cm)	168,59	9,01
Weight (kg)	67,06	9,36
MMSE	29,06	0,9

Materials

The experiment was set up in the Movement and Posture Analysis Laboratory Leuven (MALL).[30] This laboratory is equipped with a seven camera Vicon system (Vicon, Oxford Metrics, UK). Light reflected on passive markers, placed on the subject, was detected by these optoelectronic cameras at a sample rate of 100 Hz, to measure motion. Besides the six standard cameras, one was placed in front of the participant to reduce the occlusion of markers caused by multiple bending forward during the games. At least three markers per segment are needed to define the orientation and position of each segment. This resulted in a model consisting of 45 markers and 4 clusters, each containing four markers, as shown in figure 1.

Markers can be divided into two groups, calibration and tracking markers. All markers were used during a static calibration trial. Afterwards, calibration markers, shown in red on figure 1, were removed from the subject. Only tracking markers were used to determine the trajectory of the segments.

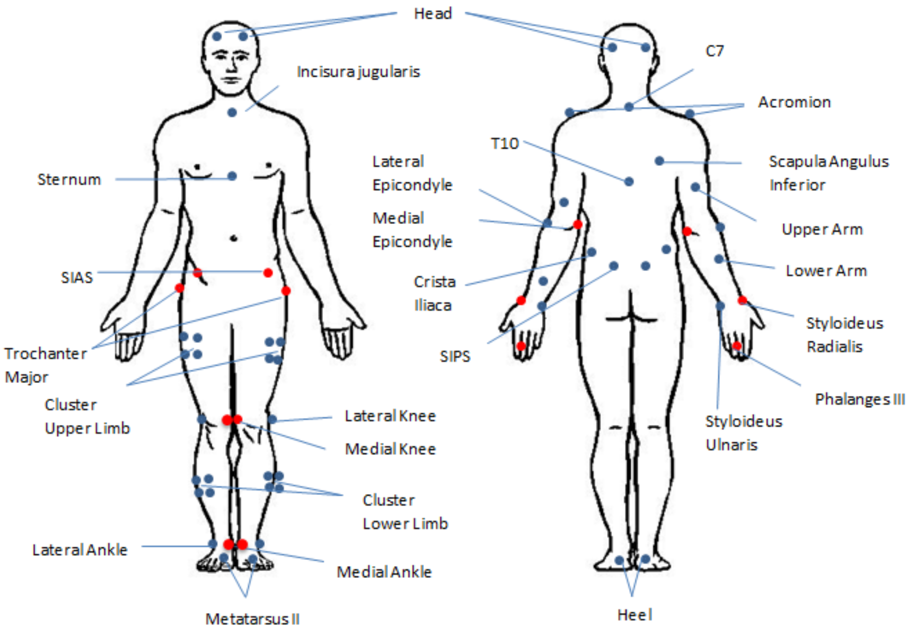

Fig. 1.: Marker placement

Muscle activity was measured simultaneously by a wireless surface electromyography system (ZeroWire, Cometa, I) with silver-chloride, pre-gelled bipolar electrodes (Ambu Blue Sensor, Ballerup, DK). The results of muscle activity are beyond the scope of this article and will be studied elsewhere. The VirBal game and FLOS task were developed and run in Dflow (MotekForcelink, NL). The virtual environment was projected with a beamer and enhanced with a surround sound system. The Dflow system was also used for the translation of movements done by the player to the avatar on the screen. The subjects' movements, during FLOS task and game playing, were registered in real time by a Kinect camera, X-box 360 (Microsoft, USA). Afterwards all marker data were analysed using Nexus software (Version 2.8.5, Oxford Metrics, UK).

Protocol

All participants were invited to the MALL to participate in the experiment. After signing the informed consent, the MMSE, had to be filled in. This is a small questionnaire to evaluate cognitive functions like memory, concentration, orientation and language.[31] For every subject, age, gender and anthropometrics were collected, surface electromyography (sEMG) electrodes and markers were placed in accordance to figure 1 and SENIAM guidelines.[32] For anthropometric data, length, weight, circumferences and length of limbs, waist, trunk and head were measured. These anthropometrics were used for the COM calculations. After attaching the markers, a static calibration trial was performed. The subject was asked to stand in a calibration position, which is standing upright with arms in supination and feet placed on hip width for several seconds. This static trial was utilized to reconstruct and manually label the model in Vicon Nexus. Before starting the games, the calibration markers (left and right medial ankle, medial knee, medial elbow, radius, spina iliaca anterior superior (SIAS), trochanter major and phalanges III) were removed. The functional limits of stability for each subject were determined by performing a custom made FLOS, more details are given below. The games tested, Kinect Adventure, Kinect Ski and VirBal were played in a randomized order. The latter consists of four mini-games, Wasps, Slingshot, Garage and Fishing, in which various aspects of balance are trained such as single leg stance, weight shifts, muscle activity and speed of movement. Only Slingshot and Wasps were games that aimed to induce challenging weight shifts and are further analyzed in this article to compare with the Kinect Ski game. After each game the subjects were given some time to rest and to fill in the IMI questionnaire about intrinsic motivation.[33]

Task

FLOS task

The functional limits of stability were determined by performing a FLOS test, whereby the limits of stability or the maximal displacements of COM possible, for every person are determined in eight different directions: left, right, posterior, anterior, left-anterior, right-anterior, left-posterior and right-posterior.

The FLOS test is developed to quantify the challenge of the weight shifts. A person is in balance when the COM is aligned above the BOS.[34,35] When the COM is displaced more to the edge of the BOS, the task becomes more challenging. However, the true limits to which the COM can be displaced show high inter-individual variability depending on anthropometric variables, muscle force and psychological variables such as fear of falling. The FLOS test is a representation of individual, functional limits of stability, as opposed to theoretical limits of stability based on anthropometry, in eight directions. The COM displacements obtained during game play, will be expressed as percentages of the FLOS value for each direction.

The participants had to move their COM, represented by a white dot, as far as possible in the direction of the red bar without bending in the hips, reaching out with a limb and without taking a step. Real time feedback on their COM position was provided. A representation of this task is given in figure 2.

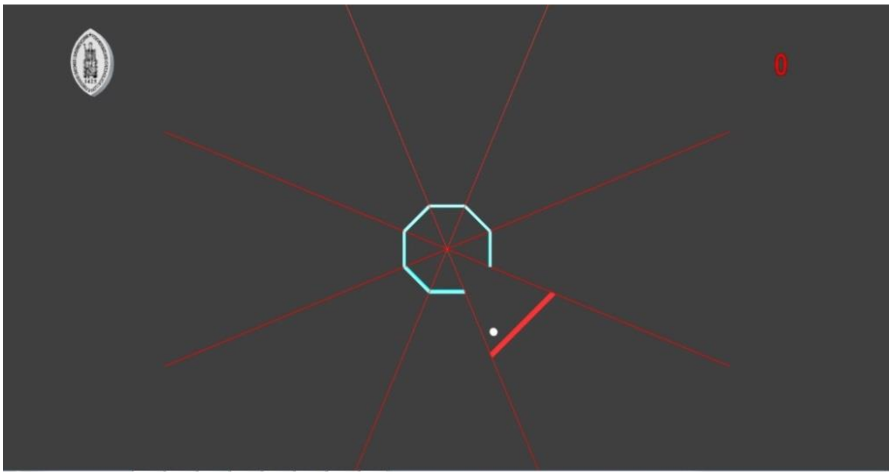

Fig. 2.: FLOS test. In this example the participant is asked to move his or her COM as far as possible in the posterior-right direction.

For the online representation of the COM, during the FLOS task as well as during the VirBal games, joint positions were tracked by the Kinect camera. The formulas of Winter for a three segment model, two legs and a trunk, were applied to estimate the COM.[36] For post-processing the COM data are recalculated using full body marker data captured in Vicon Nexus, details for this are given in the analyses and statistics section.

The starting position for the feet was standardized for all participants by tape on the ground. To make sure each participant could reach their personal limits of stability enough time was given. Three trials of the FLOS test were performed and, in every trial, all eight directions appear in a randomized order. The maximum value of the third trial was used to set the limits of movements in the VirBal games. Unless a subject made a step in the third trial, in which case the trial was not considered as accurate and had to be redone.

Games

The determined FLOS were used to set the required COM displacements in the Wasps and Slingshot games. During these games the participants have to move their COM beyond 80% of their maximal FLOS score for attaining the target. The participants were instructed not to move their feet and to use their body as a rigid structure. Wasps and Slingshot both concentrate on different aspects of balance. Wasps focusses on speed while Slingshot focusses on precision and also embraces cognitive load. Each of the mini-games were played three times in a randomised order with a transition game in between, where the subjects can rest a little before going to the next game.
For comparison we used the X-Box Kinect Ski game. This game has been tested in previous research and came out as the most challenging game regarding COM displacements.[28] During this game,

participants have to shift their COM left and right, without taking a step, to ski between poles shown on the screen. This game, as well as the Kinect Adventure game, was also played three times.

Analyses & statistics

The limits of stability and COM displacements were recalculated for the final analysis using more reliable methods than the online procedure. The motion capture data from Nexus (Version 2.8.5, Oxford Metrics, UK) were analyzed in Matlab R2016b (Mathworks, USA). All trials were labeled in Nexus using a full body linked segments model consisting of 61 markers, forming 13 segments.[37] In Matlab, spline interpolation was performed for missing marker trajectories of maximally ten frames. All trajectories are filtered with a 2nd order low pass filter on 8 Hz. Incidental steps were cut out of the COM trajectories data. This was based on a reconstruction of the movements on a stick figure and visual inspection of every trial. The remaining COM trajectories were plotted relative to the maximum FLOS of the subject, which is visualized in figure 3. Maximal displacements are defined as the maximum COM displacement over three trials in each direction.

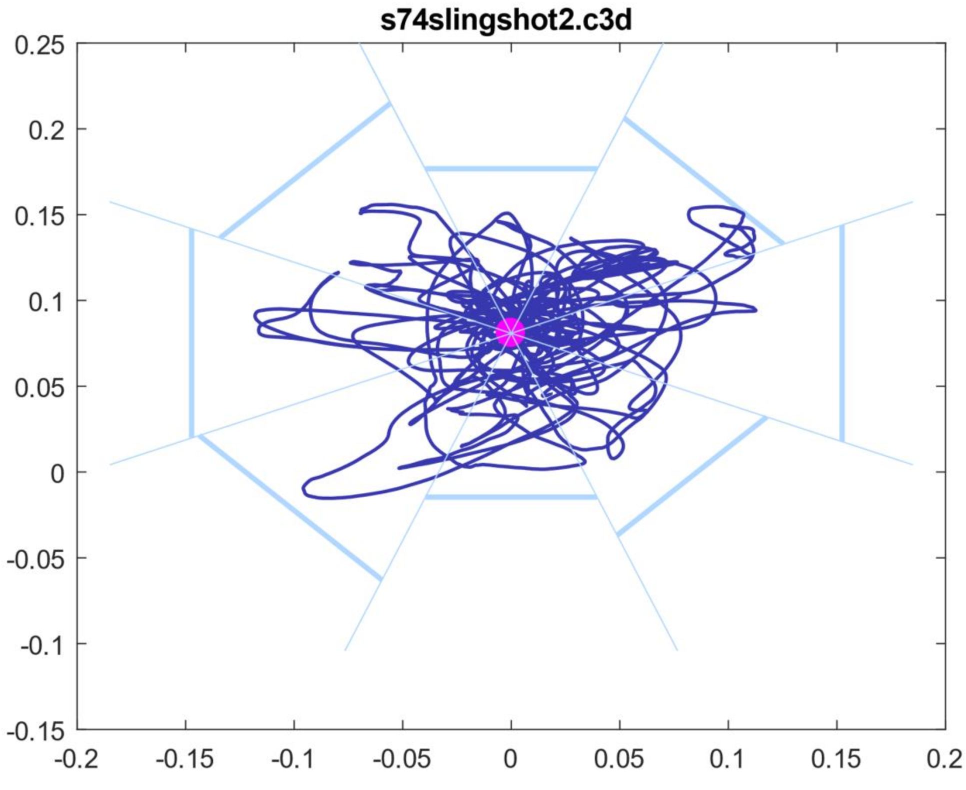

Fig. 3.: COM displacement (dark blue) in relation to the FLOS (light blue lines) in medio-lateral (ML) and anterior-posterior (AP) directions during the performance of a Slingshot game.

For statistical analyses generalized estimate equations (GEE) were used to determine whether the different games or trial numbers could explain the differences in COM displacements. GEE was chosen due to unequal variances and because it copes better with missing data. This test was performed for each direction. Post-hoc pairwise comparisons were done, using Bonferroni adjustments, to determine which games differed from each other and how the progression of trials affected the COM displacements. Level of significance was set at $\alpha = 0.05$.

Furthermore, the speed of COM displacements was compared between different games, because a higher speed of weight shifts can enhance the challenge to balance.

Results

Demographic data for all participants are shown in table 1.

COM displacements

For all eight directions, lower values for COM displacements are found in the Kinect Ski game compared to the Wasps and Slingshot game. The Wasps and Slingshot game induced an average of 80% of maximum FLOS for COM displacements in all directions, as was the intention of the game set-up, while for Kinect Ski the mean displacements are situated around 40% of the individual limits. In the left and right direction, where also the Kinect Ski game reached COM displacements up to 70% of FLOS, the differences between games were smallest. Data are shown in figure 4.

The results of the GEE analyses, including two main variables, game and trial, and their interaction effects are summarized in table 2. A significant game effect ($p< 0.001$) was found for each direction. Post-hoc analysis revealed that the Wasps and Slingshot game provoked significantly more COM movement in all directions compared to the Kinect ski game ($p< 0.001$). For the left direction, besides a significant game effect, also a significant game*trial interaction effect ($p=0.033$) was found. The mean COM displacements are similar during the three trials in the Wasps game as presented in figure 5. However, for the Slingshot game a steep increase in COM displacement is observed as trials progress. Another trend was seen in the Kinect Ski game, from trial 1 to trial 2 there was an increase in COM movement. Afterwards there was a slight decrease in COM displacements in trial 3. During the Wasps game, the subjects showed significantly larger COM displacements in the left direction, compared to the Kinect Ski game (9.531 (2.529)). Differences between the Slingshot and Kinect Ski game were only significant at the third trial. This means that the Slingshot game requires more practice. There was no main effect of trial.

Speed of COM displacement did not differ significantly between the three games. However, the values for the Kinect Ski game (0.48 (0.09) m/s) and the Wasps game (0.43 (0.08) m/s) were higher compared to the Slingshot game (0.28 (0.04) m/s).

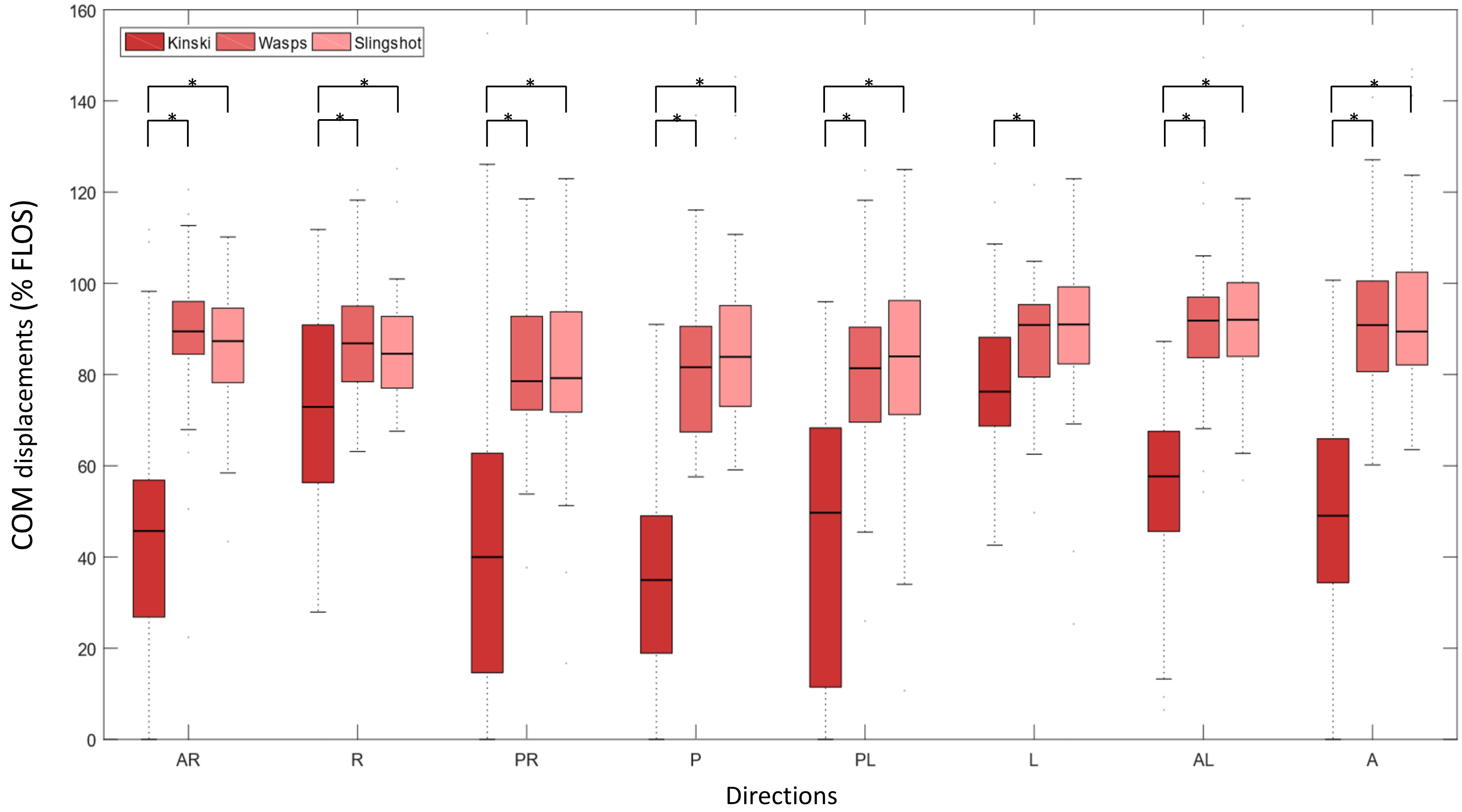

Fig. 4.: Boxplot with data for COM displacements (% FLOS) in eight directions. Kinect Ski (red), Wasps (light red) and Slingshot (pink). Boxes range from 1st to 3rd quartile, median values are represented with a horizontal line. Whiskers indicate the range of the data. Significant differences are indicated by *.

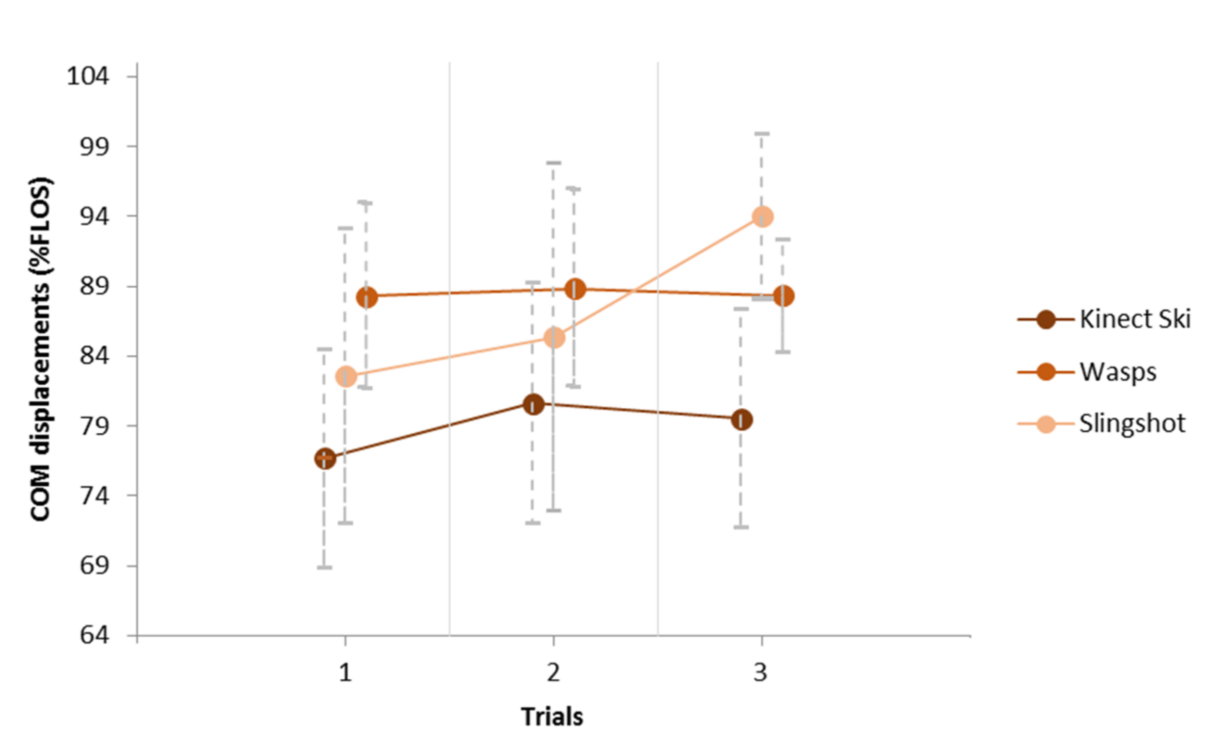

Fig. 5.: Means (% FLOS) and SD for the left direction for three trials for each game.

Table 2: P-values of GEE test, significant differences (p<0.05) are marked in bold and with *

	AR	R	PR	P	PL	L	AL	A
Game	**0.000** *	**0.000** *	**0.000** *	**0.000** *	**0.000** *	**0.001** *	**0.000** *	**0.000** *
Trial	0.37	0.853	0.759	0.804	0.770	0.123	0.973	0.417
G*T	0.246	0.299	0.166	0.167	0.513	**0.033** *	0.320	0.754

Motivation

For the IMI questionnaire both VirBal and Kinect Ski score high on interest, competence, effort, value and relatedness. As expected, only for the topic tension, which is reverse rated, scores were low. Scores are summarized in figure 6, which indicates that VirBal has better scores than Kinect Ski on some aspects of motivation, however the differences were not significant. Overall, participants show high intrinsic motivation while playing the games.

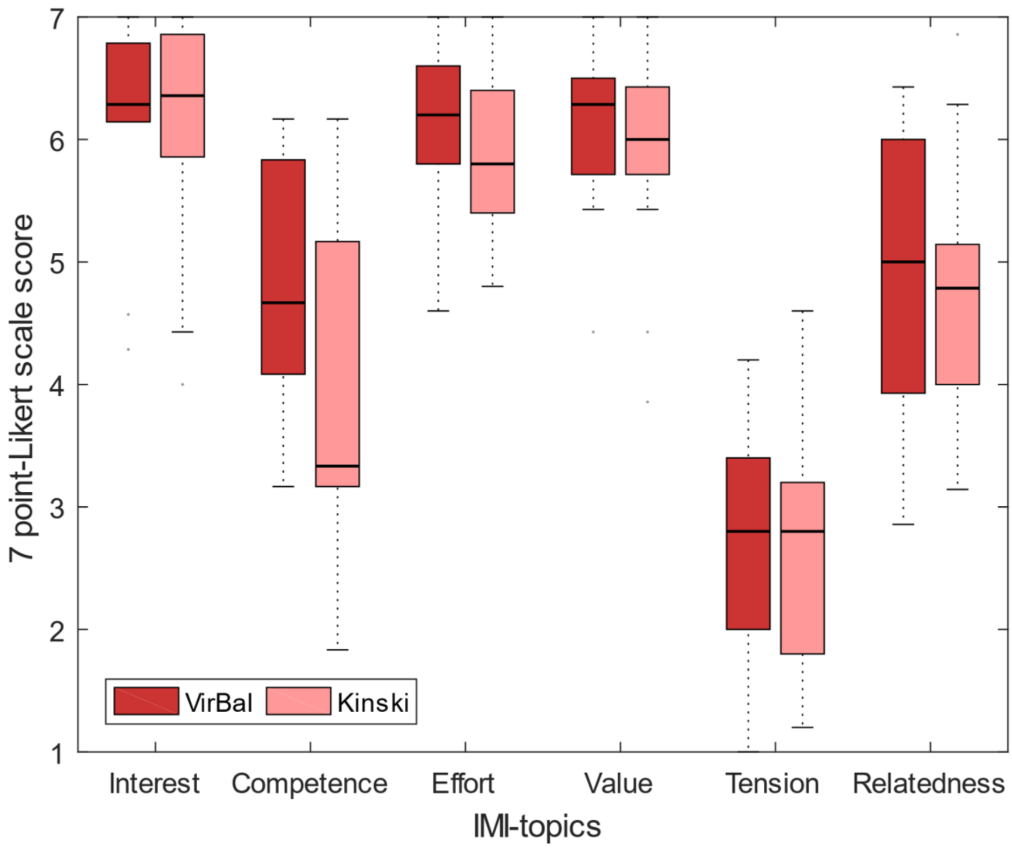

Fig. 6.: IMI scores on six topics (interest, competence, effort, value, tension and relatedness). Median values are represented with a horizontal line, whiskers indicate range of data. Boxes range from quartile 1 to 3. VirBal (red) and Kinect Ski (pink).

Discussion

The aim of this study was to investigate if the custom-made games, Slingshot and Wasps, challenge COM displacements relative to subjects' FLOS more compared to the off-the-shelf Kinect Ski game. Previously, the Kinect Ski game was shown to induce more challenging COM displacements compared to the Wii Ski game.[28] Results of the present study showed that the goal of the VirBal game, namely optimising the challenge to balance in all directions compared to the Kinect Ski game, succeeded. Additionally, the results show high intrinsic motivation for playing the Virbal game.

Challenge to balance

Across all directions, significantly lower COM displacements were observed in the Kinect Ski game compared to the VirBal game. As previously mentioned, inducing weight shifts measured by COM displacements are necessary to improve balance in elderly.[10,11,34,38] The VirBal game provokes a higher challenge to balance, which should make it more effective to train balance. Differences compared to Kinect Ski were smallest in the medio-lateral (ML) directions, where the challenge of the Kinect Ski game was also reasonably high, and up to 70% of the limits of stability. This might be due to the fact that the Kinect Ski game only focuses on ML-movements and has a lack of anterior-posterior (AP) induced movements. The difference in COM displacements between the Kinect Ski game and the VirBal game can possibly be explained by the fact that for the latter game, a participant can only score when the COM is moved more than 80% of their limits. For the Kinect Ski game, no such a restriction exists. Other possible explanations for the differences between the games are the different tasks, feedback and rewards given when playing.

Balance is maintained by the body using different strategies. The COP reflects the control of the COM by the neuromuscular system. This is done by acting a net force through the ground. The COP itself can be moved by muscle forces produced through the body.[39] In the VirBal game COM displacements are practiced in all directions, which induces muscle activation that is needed to maintain balance. Since the Kinect game induces movements mostly in ML-direction, only certain muscles and balance strategies will be trained and reinforced. However, the VirBal game will provoke a combined muscle activation that more fully probes the stability limits and induces more complex control strategies during task performance. Given the fact that daily life activities are not only in ML-direction, the VirBal game could train balance in a more functional manner. Currently, little research is conducted on COM displacements in exergames, which makes it difficult to compare our results with existing literature.

Van Diest et al. showed that the Kinect system, a simple and relatively cheap technology for movement registration which is used during the games, accurately identifies movement patterns and can be used to play balance games at home.[42] Using the Kinect in a combination with the FLOS game, as seen in the VirBal game, individual limits can be used to change the difficulty of the games. By this, everyone can train on his or her personal limits to improve balance. Since training on personal adapted levels, which optimizes intensity for each person, is mentioned as an important recommendation in balance training, this is a big advantage of the VirBal game that is not met in the Kinect Ski game or other off-the-shelf games.[43]

During the VirBal games, COM displacements are used to move the items on the screen and play instead of COP displacements. The latter is often used in off-the-shelf movement games.[21,44] Large COP movements can be made without shifting the body COM a lot, while recommendations state to include challenging weight shifts as an important component in balance training.[10,11,34,38] Because of this, it was important to prove that the COM displacements demanded as percentage of the FLOS in the developed VirBal game are higher compared to the existing, commercial exergames, using COM displacements to move the avatar of the game. All trials were conducted in a controlled environment to improve standardization. Balance tasks can become more challenging by covering a broader range of motion or speeding up an exercise. To control for this, a post-hoc comparison of within-subject speed was performed and showed similarity for the different games.

In the left direction, a significant difference between games was only seen for the Wasps game versus the Kinect Ski game. The Slingshot game did not show significantly more COM displacements, except for the third trial, suggesting that subjects needed more familiarization to increase their displacement in the Slingshot game. A significant game-trial effect indicated a clear difference between trials for the Slingshot game, with increasing COM displacements going from trial 1 to trial 2 and an even steeper increase from trial 2 to trial 3, whereas no change over time was seen for the other games. The Slingshot game focusses on balance but also adds a cognitive component to the game. It took the participants a couple of trials before they understood the aim of this game and how to play it. This can be a possible explanation for the difference between trials. Over time, the aim is to learn the participants to move their COM more in order to gain rewards in the game. To summarize, results of this study indicate higher COM displacements in all eight directions for the in-house developed VirBal game compared to the Kinect Ski game. Further, a learning effect was seen in the Slingshot game. Both higher COM displacements and the learning effect are in line with existing recommendations from literature, namely to increase and train COM displacements.[38]

Besides the physical aspect of balance training, also adherence to the training program is necessary.[10] A high dose of continued balance training is prescribed in literature to improve functional balance in healthy elderly.[10,14] Exergames were developed to improve adherence to the program by increasing the fun aspect while practicing balance. In this study, enjoyment was measured using the IMI questionnaire, containing questions about interest, competence, effort, value, relatedness and tension. Except for tension, all games scored high on every topic. Tension, a reverse rated topic, had low scores for every game, indicating a good result. These scores indicate a high intrinsic motivation while playing the games. This is an important feature, considering the high dropout rates in widespread exercise programs for elderly.[10,17,45,46] No big differences were found between the three games, possibly due to a ceiling effect in the motivation of participants. If every game scores high, it is more difficult to find differences between them due to the limited range of possible scores.

Limitations

Only sixteen subjects were tested, however, this study had enough power to prove significant differences and consistency for all directions in COM displacements between the different games. Subjects engaged voluntarily after responding to a flyer distributed in the sport facilities of the KU Leuven university or by snowball sampling. All participants had a rather good stamina, without any musculoskeletal-, neurological- or vestibular problems, as indicated in the exclusion criteria. These factors may bias the results and caution is needed when generalizing these results to a broader population. Further, it took several trials before the subjects understood the aim of the games and how to play it. This is possibly due to the fact that the games are only played three times, which indicates that support is needed for the older subjects when learning to play the games. Another feature that needs to be improved in the future regards technique and visibility by the Kinect during the exercises. Elderly should receive support with the set-up of the games to make sure the Kinect is placed in a good position to play the games and measure the individual limits of stability. When a subject bends the hips too much in the sagittal plane, it becomes difficult for the Kinect to recognize the body and it also made it difficult to analyze the data. Also, the proper performance technique for certain exercise should be explained to make sure the participant is doing the exercises in a correct way. Finally, the frames where a participant moved their feet or performed a jump had to be manually deleted. This was done since the game focuses on COM displacements without moving the feet. For this, the data is reviewed and processed by different raters, which can lead to involuntary variability. However, by discussing several trials and doubtful points, the risk of bias is limited to a minimum.

Further recommendations

As mentioned before, additional research is needed in the future. First, besides the importance to train balance through challenging weight shifts, also muscle strength is an important factor to consider in fall prevention.[20] Analysis of the muscle activity was beyond the scope of this article, but will contribute to a more thorough vision on the components needed for the development of a balance program. Within this study both sexes were tested, which contributes to generalization of the results, however, further research should be conducted on a larger sample size for a longer period. Before using the games in broader settings like revalidation centers, hospitals and day care centers, their use need to be tested in more specific populations.

Conclusion

To conclude, results of this study revealed more COM displacements towards the limits of stability for the in-house made VirBal game compared to commercial exergames, suggesting a more challenging task for balance. This fact can be extended to all games using the currently available and affordable Kinect software. Further, by using the FLOS test, the game difficulty can be adjusted to the level of the player. High scores on the IMI-components demonstrate intrinsic motivation while playing the games. Together, these outcomes show the possible usefulness of the game in day care centers and independent living elderly for training to prevent falls, however this has to be tested first. Furthermore, this game could be extrapolated and maybe used in rehabilitation settings.

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