EFFECTS OF EXERGAMING ON POSTURAL CONTROL, SENSORY REWEIGHTING AND MEDIOLATERAL STABILITY IN OLDER ADULTS

Ph.D. Thesis

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LIST OF ABBREVIATIONS

30-sec CST:	30-Second chair stand test
ABC:	activities-specific balance confidence
AE:	aquatic-based exercises
ANOVA:	analysis of variance
AP:	anteroposterior
APA:	anticipatory postural adjustments
BBS:	Berg balance scale
BMI:	body mass index
BOOMER:	balance outcome measure for elder rehabilitation
BOS:	base of support
BT:	balance training
CoG:	center of gravity
CoP:	center of pressure
CPA:	compensatory postural adjustments
FGA:	functional gait assessment
FRT:	functional reach test
FSST:	four-square step test
LOS:	limit of stability
ML:	mediolateral
Mini-BESTest:	mini balance evaluation system test
m-CTSIB:	modified clinical test of sensory interaction in balance
LE:	land-based exercises
LOS:	limit of stability
LOS-RT:	limit of stability reaction time
LOS-V:	limit of stability velocity
OLST:	one-leg stance test
RCT:	randomized controlled trial
RT:	resistance training
SD:	standard deviation
SOT:	sensory organization test
SPPB:	short physical performance battery

TUG:	timed up and go test
TUG-cog:	timed up and go dual-task
VOR:	vestibulo-ocular reflex
VR:	virtual reality

1. INTRODUCTION

Slipping, stumbling, or any other kind of unintentional loss of balance that results in a fall and subsequent hospitalization due to injury, is a serious global concern for people over the age of 60 according to the World Health Organization[1].

In Hungary, according to the Institute of Health Metrics and Evaluation, the fifth cause of death and disability was falls; and overall, among 100,000 people, 1045 citizens suffered an injury or died due to falls[2]. According to the National Bureau of Statistics, there are 2.6 million people aged 60 or above in Hungary, which is almost 1/3 of the total population, and of this age group, 60% were women [3]. Consequently, interventions that improve the quality of life of senior citizens are essential. Therefore, it is important to design training programs that can help prevent future falls and their potential consequences, such as immobility, premature nursing home placement, surgical, lifesaving interventions, or permanent disability.

To perform our daily activities, to maintain various positions, to automatically respond to voluntary body and extremity movements, and to react to external disturbances balance and postural control are essential. Despite balance being a commonly used term, there is no universal definition of human balance[4]. In order to maintain a specific posture, such as standing, sitting, performing voluntary movements, or reacting to external disturbances, such as a push or a slippery surface, we have to keep our center of gravity (CoG) within the base of support (BoS)[5]. If an inanimate object's line of gravity falls out of the BoS, the object loses its equilibrium and it will fall or move. Humans, on the other hand, have the ability to sense if their stability is compromised and consequently activate the body's postural control to compensate the force of gravity in order to prevent falling[4]. Based on the findings of Shumway-Cook and Woollacott, balance can be categorized as static/dynamic steady-state (i.e., keeping a steady position while sitting, standing, and walking), proactive (i.e., feed-forward strategy to a predicted disturbance), and reactive (i.e., feedback strategy to compensate a disturbance)[6]. Thus, the limit of stability (LOS) depends on a subject's biomechanics, the requirements of the task, and the type of surface the person is standing on[7].

The review of Surgent et al.[8] suggests that balance is a series of complex processes, in which not only a few specific regions of the brain play important roles but rather almost every region of the brain. In particular, certain structures, such as the cerebellum, the basal ganglia, the thalamus, the hippocampus, the inferior parietal cortex, and the frontal lobe (defined in general) may be of key importance in balance skills[8]. Due to the complexity of postural control, it can no longer be recognized as one system or a set of righting and equilibrium reflexes[9].

According to Horak (2006) "many systems need to be evaluated to understand what is wrong with a person's balance"[9]. Postural equilibrium ensures the coordination of sensorimotor strategies to stabilize the CoG during both self-initiated and externally occurring disturbances in postural stability[9]. To interpret complex sensory environments sensory inputs from somatosensory, visual, and vestibular systems must be processed. If the sensory environment changes, subjects need to re-weight their relative dependence on each of these sensory systems to preserve their stability for example when a subject moves from one sensory context to another, such as from a bright room to a poorly lit basement[9]. Thus, to plan an adequate balance training or fall prevention program it is important to understand the multiple mechanisms underlying postural control[9].

1.1 Effects of aging on balance

Age-related declines in balance are well documented[10-13]. Age-related deficits may manifest in cognitive function[13], in neuromuscular control mechanisms[15-16], and in the following 3 sensory systems: the visual[17], the somatosensory[18], and the vestibular[19].

There is a connection between cognitive functioning and the risk of falling since age-related deterioration of the frontal cortex and the alterations to the brain's white matter can lead to balance problems[20]. Slight changes in cognitive functioning might result in poor judgment and decision-making deterioration in executive function[20]. Decreased attention span, slower processing speed[21]; and the decline in verbal reasoning[22] could also contribute to falling. These particular problems challenge subjects with mild cognitive impairments, as many of our daily activities are dual-tasks (e.g., when talking and walking at the same time or speaking on the phone while packing in the kitchen)[23].

Age-related, involuntary loss of skeletal muscle mass and strength (muscle atrophy) is called sarcopenia, which is one of the most important causes of functional weakness and loss of independence in older adults[24]. Aging causes changes in motor unit morphology and properties, which results in impaired motor performance[25]. As a result of that reduced maximal strength and power, slower contractile velocity and increased fatigability occur[25]. In a meta-analysis, associations between sarcopenia, falls, and fractures have also been highlighted[26].

With advancing age, the normal function of eye tissues deteriorates as well, which increases the incidence of ocular disorders. The most frequent causes of visual impairment in the elderly are presbyopia, age-related cataracts, age-related macular degeneration, primary open-angle glaucoma, and diabetic retinopathy[27]. However, there are other common visual problems that older adults often experience: impaired spatial contrast sensitivity, scotopic sensitivity loss, and delayed rod-mediated dark adaptation, as well as a slowed visual processing speed[28]. There are correlations between low visual acuity, poor contrast sensitivity, depth perception, visual field impairment, and falls[17]. Therefore, it is important to understand how visual functions can be associated with fall risk[17].

Recent clinical evidence suggests that aging results in declines in the morphology and physiological function of various sensory structures (e.g., muscle spindles, Golgi tendon organ, and articular receptors)[18]. In addition to that, the preferential loss of distal large myelinated sensory fibers, or receptors, the impairment of the distal lower-extremity proprioception, and the deterioration of vibration and discriminative touch are consequences of healthy aging as well[18]. The structure and function of the somatosensory system deteriorate with aging, which can potentially result in balance problems and risk of falls in older adults[18].

Aging causes a degenerative effect not only in the previously mentioned systems but also within the vestibular system[29]. The progressive accumulation of changes with time in the vestibular system is a multifactorial process. The process of aging affects both the peripheral organs (e.g., hair cells, otolith organs, semicircular canals) and central circuits, from the peripheral end-organ to the brainstem to the cerebellum and to the cerebral cortex[29]. Since the inner ear senses head movement and spatial orientation and produces reflexes to stabilize gaze and maintain posture, any deficit of the vestibular system may result in postural control problems[29].

In respect of, postural control should not be considered as one system, but a complex motor skill gained from the interaction of numerous sensorimotor processes[30]. However, various studies have shown that older individuals tend to use and rely more on proprioception rather than visual and vestibular information for postural motor control. This dependence on the proprioceptive system also increases with age[31-32]. In direct contrast to this, Haibach et al.[33] found that older adults tend to rely more heavily upon their visual input rather than the other sensory systems as a way to compensate for age-related deficiencies. According to previous studies[13,34], adults tend to experience difficulties in switching quickly between various reliable sensory inputs, which ultimately may contribute to an increased risk of falls. However, Allison et al.[35] suggest that this particular process is not impaired among the target population as a direct result of aging.

Regardless of whether sensory reweighting deteriorates or remains unchanged with age, therapists should aim to plan programs that can develop these previously mentioned sensory systems and thus decrease the risk of falls.

1.2 Sideward falls and the importance of ML stability in older adults

Hadjistavropoulos et al.[36] showed that there are strong associations between reduced balance performance and fear of falling, which can lead to a vicious circle, where people avoid physical activities that ultimately contribute to frailty. A study demonstrates that frailty is a common condition among elderly patients with a hip fracture[37]. It has been confirmed that community-dwelling women over the age of 65 are at least two times as likely to suffer hip fractures due to a fall when compared with men[38]. In one study, osteoporosis-related fractures in Hungary were investigated and thus offered incidence data not only on the hip but also on several other fractures between 1999 and 2003, when the total population was approximately 10 million inhabitants[39]. According to the data reported in this 5-year period, 404,380 Hungarian women and 206,009 men over the age of 50 had at least one fracture, and a possible reason behind this phenomenon might be attributed to the difference between each gender's change in the level of sex hormones during various stages in life[39]. The changes may contribute to older women having a more significant decrease in bone mineral density[40]. Besides age-related hormonal changes, multitasking increases women's gait variability, and this has a direct relationship to the prevalence of falls[41]. Furthermore, elderly women with an abnormal balance while walking are more likely to fall[42]. According to the findings of Qazi et al.[43], a static posturography test demonstrated that the mediolateral (ML) component of postural sway is most strongly associated with long-term fracture risk in postmenopausal women. In addition to that, sideward falls are the most frequent cause of hip fractures among older adults[44], meaning that it is of key importance to detect with posturography quantifiable information on body sway that cannot be visible to the clinicians' naked eyes[45]. Signs of instability are sometimes not immediately apparent in the clinical setting, but sensitive measurements, such as postural sway, can predict the likelihood of falls[43]. For this reason, it is essential to implement training programs that improve sensorimotor control in the critical ML direction. According to Rosen et al.[46] most injuries due to falls occur at peoples' homes, especially in the bathroom because performing everyday movements such as getting up from a chair, stepping out the bathtub, taking out a mug from a cupboard, climbing stairs, rushing to pick up a ringing phone is not as easy as they might seem to be.

1.3 Improving older adults' postural control

Deficiency of any of the above-mentioned components of postural control may remain undetected until the first experience of a fall. Therefore, to reduce the effects of age-related changes on balance, choosing a suitable training method that improves all levels of impaired postural control is essential. There have been several attempts in physiotherapy during the last decades for the prevention of falls and balance impairments in older age. Ideally, a training program is safe, results a good level of physical fitness, and improves every previously mentioned system postural control depends on.

1.3.1 Types of training for improving older adults' balance

It has been suggested that resistance training (RT) is a form of physical activity for the elderly that could be effective and safe[47]. This training method is capable of reversing the effects of sarcopenia[47] and can improve body posture, balance, and physical resistance[48-49]. As a result, RT for older adults may result in neuromuscular improvements, and it may increase muscle mass, strength, and functional capacity[50]. Keating et al.[51] composed a systematic review of randomized controlled trials (RCT) within an aging population that evaluated the general impacts of a resistance training protocol on key outcome measures in aspects of gait and/or balance. Most of the studies applied the methodology of the American College of Sports Medicine Position Stand on Progression Models in Resistance Training for Healthy Adults to design the sets and repetitions to increase muscle mass through hypertrophy. The duration of the programs was from 6 to 32 weeks, but 12 weeks was the usual training period. Among the studies the most common tests used to assess balance were: the Timed Up and Go (TUG), the single-leg stance, tandem or bilateral stance, the body's center of oscillation, the Short Physical Performance Battery (SPPB), 10-m walk speed, Functional Reach Test (FRT), Berg Balance Scale (BBS), and the 400-m walk test. Based on the analyzed studies' results this review concludes that RT is an adequate training method to improve balance in people over 65 years of age[51]. RT has a beneficial effect on both gait and balance in an aging population. A training program that contains resistance exercises enhances gait parameters, but specifically straight-line walking speed, in older adults[51].

In a systematic review, the authors aimed to establish evidence-based dose-response relationships in balance training (BT) modalities (i.e., training period, training frequency, training volume) in healthy older adults through the analysis of RCTs[52]. The investigated studies were coded for the following criteria: training modalities (i.e., training period, training frequency, training volume) and balance outcomes [static/dynamic steady-state (i.e., keeping a steady position during standing and walking), proactive balance (i.e., awaiting of a predicted perturbation), reactive balance (i.e., responses to unexpected perturbation) as well as balance test components (i.e., combined testing of different balance components as the BBS)]. The analyzed studies were eligible for inclusion if their participants were healthy older adults with a mean age ≥65 years; it contained a BT protocol comprising static/dynamic postural stabilization exercises, and if the study tested at least one behavioral balance outcome (e.g., gait speed). The analyzed 23 RCTs revealed that BT (neuromuscular training, proprioceptive training, sensorimotor training, instability training, or perturbation training) is an effective method to improve healthy older adults' balance performance. The review of Lesinski et al.[52] demonstrated that BT is effective in improving measures of static/dynamic steady-state, proactive and reactive balance, as well as performance in balance test batteries in healthy old age. Based on the findings of this review, an effective BT protocol is characterized by the following independently considered training modalities to improve balance performance in healthy older adults: a training period of 11–12 weeks, three times per week, a total number of 36–40 training sessions, a duration of 31–45 min of a single training session, and a total duration of 90–120 min of BT per week[52].

In the review of Kim et al., the effects of aquatic-based exercises (AE) and land-based exercises (LE) on dynamic balance have been compared in older adults aged 65 or above[53]. In the analyzed studies, tests for dynamic steady-state balance (e.g., 5-m walk test, 10-m walk test, backward tandem walk), proactive balance (e.g., FRT, TUG, 8-ft up-and-go test), and balance test components (e.g., BBS; and BOOMER; Balance Outcome Measure for Elder Rehabilitation) have been applied. The AE programs varied substantially in the included studies in regards to the intervention duration (45–60 min), frequency (1–5 sessions per week), and total duration (4–20 weeks). The AE programs offered gait exercises, challenged mobility, and contained stretching, stabilization, resistance, balance, endurance, strengthening, aerobic training, and Ai Chi (Tai Chi in water). Apart from the two Ai Chi studies the exercise training groups were identical or similar in types of exercises, volume, emphasis, and objectives. This review did not confirm the statistical superiority of AE over LE programs on dynamic balance. The analyzed results imply that AE can be an appropriate alternative to LE in terms of making clinically meaningful improvements in balance. Since both AE and LE have different advantages (during AE there is no risk of falls, whereas LE provides load on bones), therapists should carefully select the appropriate exercise mode that matches each participant's preference[53].

In a systematic review, the effects of Tai Chi on body balance in people over 60 have been analyzed[54]. This review assessed 19 studies, and only four of them confirmed definitively the effects of Tai Chi on the body balance in older adults[54]. In the evaluated studies, a variety of balance measures were used to investigate the effects of Tai Chi on balance or fall prevention.

Functional measures (e.g., the unipedal stance with eyes open or closed, or the tandem stance) were the most frequently used measurements. Platform stability tests were applied only in six studies and these posturography analyses resulted in more precise information and more precise measurements (on the length of time a subject performed a particular sway, shifts in the center of gravity, the precision of body sway) on balance. This review suggests that participation in Tai Chi can improve the body balance of elderly people, nonetheless, the effectiveness of this training type compared to other programs remains unclear[54].

1.3.2 Exergame training to enhance older adults' balance

Exercise games that are played in a virtual, but realistic environment (exergames) have become popular in various fields of research and rehabilitation recently, although these products primarily did not serve any therapeutic purpose. In the last decade, non-immersive virtual reality (VR) (without the use of a head-mounted device) exergame trainings with the Kinect system have been proven to be effective in improving postural control among older adults[55-59]. In a review, 12 RTCs have been analyzed to summarize the effects of exergames on mobility and balance in comparison to no exercise or health education in older adults without neurological conditions[60]. In the evaluated studies, physical exercises with Nintendo® Wii, Xbox®, and Playstation® were used most commonly. Pacheco et al. defined the primary outcomes assessed as follows: (i) postural balance measured using valid instruments such as BBS, Center of Pressure (CoP) parameters assessed by force platform, Tinetti balance test, Balance Master System, and Activities-Specific Balance Confidence (ABC); and (ii) functional mobility measured with physical performance instruments such as the Short Physical Performance Battery (SPPB), FRT, the Functional Gait Assessment (FGA), the 8-ft up and go test, the 30-s chair stand, and the TUG[60]. A total of 1520 older adults participated in the analyzed 12 studies. Their mean age was 76 ± 6 years. The mean of exergame training time was 825 ± 342 minutes. The mean number of sessions was 21 ± 10 and the trainings' duration varied from 4–16 weeks. This review highlights that exergames require cognitive attention and control for external stimuli and elicit fast reaction times. Based on the analyzed results, both types of exergames (namely commercial and serious games, which are designed for specific training purposes) had similar effects on balance. This review suggests that in comparison to no intervention, exergames developed balance and mobility in older adults without neurological conditions[60].

Yang et al. compared the effects of Kinect exergames and conventional exercises among older adults[61]. In this RCT, study subjects (n=20) were assigned either to the exergame or to the conventional exercise training group. For the 5 weeks-long program (2 times a week, 45-minute sessions) the following balance assessments were used before and after the treatment: 30-Second Chair Stand Test (30-sec CST), TUG, FRT, and One-Leg Stance Test (OLST) respectively with eyes open and closed. The results of this study showed that both treatments were beneficial in enhancing the participants' balance performance. Noteworthy is the fact that overall balance ability and improvement in functional reach were more enhanced following Kinect exercise training in comparison with traditional exercise[61].

2. AIMS

Very few studies have investigated the effects on balance improvement for older adults for commercially available Kinect gaming training compared to exercise training, conventional physical therapy, or a no-intervention control group[55,57, 62]. In our initial study, we compare the effects of these different types of training groups at the same time in healthy older adults, focusing on only the functional balance tests complemented with a posturography evaluation. To investigate if the Kinect training program is more effective than the conventional balance training, it was essential to apply balance tests that represent balance abilities necessary for everyday life movements and natural body movement patterns.

In the past 3 years, the effect of exergaming on sensory reweighting among older women has received little attention despite its clinical importance for physiotherapists. Because of the limited number of studies available on this topic, this usability study is focused on examining the potential effects of Kinect exergame training on sensory reweighting and balance in the ML direction in healthy older women. Despite the described beneficial effects on balance from exergaming, the exact mechanisms of how exergaming improves the balance ability of older adults still remain unclear[63]. It has been suggested that one of the underlying effects of exergames might originate from sensory reweighting. Body sway–based assessments such as the Sensory Organization Test (SOT) or the Modified Clinical Test of Sensory Interaction in Balance (m-CTSIB) are sensitive tools for measuring sensory feedback reactions and processes during static stance. These measurements confirmed changes in sensory reweighting following exergaming in patients with Parkinson's disease[64], healthy and young adults[65-66], older adults[67], women with fibromyalgia[68], and healthy women[69].

2.1 HYPOTHESIS I.

Our initial study aimed to confirm that Kinect training using commercially available games might be more effective than conventional balance training on improving the functional balance of healthy older adults.

2.2 HYPOTHESIS II.

We investigated the effect of the Kinect exergame training on postural control in the crucial mediolateral direction in women aged over 60.

2.3 HYPOTHESIS III.

We examined whether Kinect exergame balance training might have a beneficial impact on sensory reweighting in women aged over 60.

3. MATERIALS AND METHODS

3.1 Study design and participants' enrolment in the study of the conventional balance training versus the Kinect exergaming program

Healthy community-dwelling older adults (free from known musculoskeletal, neurological, and cardiopulmonary disorders), older than 60, were recruited for our study on improving balance abilities through local announcements in senior centers of the city Szeged, Hungary. Exclusion criteria included self-reported cognitive impairment, disorders of the heart and circulatory system, musculoskeletal, respiratory, and autoimmune diseases, neurological conditions, hearing or vision loss, artificial limbs or prosthetics, sores on lower limbs or feet, and taking medication that could affect the postural control. Altogether 117 volunteers signed up for the training program, but due to any of the exclusion criteria, 24 subjects had to be excluded from the study, while 3 volunteers declined to participate. On the arrival of subjects (on a first-come, first-served basis), 90 participants were allocated either to the Kinect training group or to the conventional balance training group, or the no-intervention control group. Subjects were kept unaware of the method of allocation and about different types of groups, but the authors were not blinded to the group assignment. Our volunteers were informed about the start and procedure of the study one by one. There were 30 participants in the Kinect training group, whereas 7 and 8 subjects, who were allocated to the conventional balance training and control group respectively, had to be excluded from the study due to their scheduling issues and loss of interest in the evaluations. Our participants performed casual daily activities but did not participate in any organized physical training exercise program. To avoid any bias, for the duration of our study we asked our participants not to be engaged parallel in any other structured physical exercise or balance training program. The Ethics Committee of the University of Szeged, Hungary, approved the study (registration no. 125/2015 SZTE). Signed informed consent was obtained from all individuals before they participated in the research. All procedures were performed according to the Declaration of Helsinki. Our study ran between July and November 2015.

3.2 Study design and participants of the Kinect exergaming usability study

For this study, healthy, community-dwelling older women above the age of 60 were recruited via local announcements in the senior centers within the city of Szeged, Hungary. Exclusion criteria included self-reported comorbidities (such as cognitive impairment; disorders of the heart; circulatory, musculoskeletal, and respiratory ailments; autoimmune diseases; and neurological conditions), hearing or vision loss, prosthetics or artificial limbs, wounds on lower extremities, and the use of medication that could affect balance or participation in other organized physical training exercise programs. Twenty active, community-based volunteers signed up for the training program; however, due to the exclusion criteria, only 14 of them could participate in the study. The Ethics Committee of the University of Szeged, Hungary, approved the study (registration no. 125/2015 SZTE). Signed informed consent was obtained from all individuals before they participated in the research. All procedures were performed according to the Declaration of Helsinki. Our study ran between July and November 2015.

3.3 The demographic data in the study of the conventional balance training versus the Kinect exergaming program

Altogether 75 subjects participated in our study. The demographic characteristics of participants in the three groups are presented in Table 1. There were no significant differences between the training and control groups in age, sex distribution, and BMI ($p<0.05$).

Table 1. Demographic characteristics of participants

	Kinect balance training group	*Conventional balance training group*	*Control group*	P
N	30	23	22	>0.05
Age (years)	69.57 ± 4.66	69.12 ± 4.19	67.18 ± 5.56	>0.05
Sex distribution (male/female)	1/29	1/23	4/18	>0.05
BMI (kg/m^2)	26.21 ± 2.60	25.95 ± 2.60	27.09 ± 5.45	>0.05

BMI, body mass index.

3.4 The demographic data of the Kinect exergaming usability study

Overall, 14 female volunteers (mean age 67.87±4.96 years, mean BMI 25.21±2.3 kg/m^2) participated in the study without any dropouts.

3.5 Training types in the study of the conventional balance training versus Kinect exergaming program

3.5.1. The Kinect training

Prior to the study, the participants did not have any experience with exergames, thus before the very first training, the group was given an introductory demonstration on how to play the gesture-controlled videogames. Subjects were trained with the Microsoft Xbox 360 Kinect (Redmond, WA) videogames. Kinect is a motion-sensing input device produced by Microsoft for Xbox 360 videogame consoles and is based around an RGB camera, providing among others full-body 3D motion capture. The pictures of the game were projected on the wall, and with the help of the Kinect sensor. Before the training, we conducted a pilot testing exergaming session where subjects were grouped into matched pairs based on age, physical abilities, understanding the tasks in the virtual environment, and summed points reached in the pilot gaming session. Subjects participated in the training sessions three times a week for 6 weeks (altogether 18 times), conducted by physiotherapists. Each training session took 30 minutes for each of the participants. During the 30-minute activity, there was *1-minute transition time between the games, when players could take a rest. Games that require more predictable movements and more simple elements (e.g., bowling or football, skiing, and just dance) were played in half of the total game time and those games that necessitate higher attention and fast reaction times (20.000 Leaks, Space Pop, Reflex Ridge, River Rush) were chosen to play for the second half of one training session. Participants played the same type of games in the same order on each gaming day to avoid bias. Relying on the methods of previous studies[55, 70-71] that effectively used Kinect games for rehabilitation or improving balance in our research, we applied games that also contain patterns of everyday functional movements, which model usual natural motions, that is, reaching and leaning toward something, upper limb movements while static standing, weight shifting, forward, backward, and side stepping, squatting, lunging, and hopping. Players' adaptation and progression were also considered, and therefore, the level of difficulty of the games was continuously set during the training.

3.5.2 Conventional balance training

Before the training, we conducted a pilot testing balance training session where subjects were grouped into matched pairs based on age, physical abilities, and understanding of the exercises. Participants who performed conventional balance training were trained for 6 weeks, three times a week (altogether 18 trainings). During the interventions, volunteers were instructed by a physiotherapist on how to complete the exercises. The balance training was performed in an exercise room at a clinical physiotherapy department. Based on the studies of Zhuang et al.[72] and Halvarsson et al.[73] our training targeted balance control in specific situations that can occur in daily life, such as obstacle course, applying cognitive tasks with simultaneously performed physical exercises. On the abovementioned methods of researches[72-73], our training consisted of three parts: the first few minutes of the training session contained light warm-up exercises (arm, leg, and neck movements, marching in place) followed by the main part of the training, where participants performed static and dynamic balance exercises that also included reaching and leaning, weight shifting, forward, backward, and side stepping, change of direction exercises, squatting, lunging, and hopping tasks. The sessions ended with a few minutes lasting cool-down part, including stretching and breathing exercises.

3.5.3 Control group

Members of the control group received no balance training, only pre- and post-measurements (in 6 weeks).

3.6 The training of the Kinect exergaming usability study

The applied equipment consists of a motion-sensing RGB camera named Kinect, and Xbox 360 console, and video games developed by Microsoft. During the training, pictures of the game's scene and a player's avatar were projected onto the wall via the camera's full-body 3D motion capture. Before the training program commenced, volunteers had not had any experience with exergames or any of the previously mentioned devices, and so it was important to have an introductory meeting prior to the first training session where instructions were given on how to play the gesture-controlled video games and an opportunity to experience them first-hand. The training took place at Albert Szent-Györgyi Clinical Center's Physiotherapy Department 3 times a week over a 6-week period (total of 18 visits). These sessions were assisted by physiotherapists. Participants were instructed to wear a comfortable outfit and safe footwear for the 30-minute training. Games were chosen based on the type of movements their performance required, with the main aspect being that games had to contain patterns of everyday functional movements that modeled usual, frequent natural motions. Commercially available Kinect games were played by the participants which demanded continual displacement of the participants' CoG, transference of weight between lower limbs, and lateral trunk bending, and frequent sidesteps. The motor stimulation during gameplay required balanced reactions and continuous postural adjustments associated with fast movement of the legs and arms. During the first half of the training sessions, games that consisted of more foreseeable movements and simple elements (e.g., football, skiing) were played. Other more complex games that needed higher cognitive attention and fast reaction (20.000 Leaks, Space Pop, Reflex Ridge, River Rush) were selected to be played in the second half of the training sessions. All participants played the same type of games in pairs, in the same order on every training occasion, but were never allowed to play the same game on 2 consecutive training sessions. During the training, the players' adaptation and progression, as well as the level of difficulty of the game, were continuously recorded and modified based on each participant's overall ranking in the game. Between each game, there was approximately a 1-minute pause so that players could take a short break.

3.7 The applied measurements in the study of the conventional balance training versus Kinect exergaming program

The outcome measures were recorded before the training (at baseline) and at the subsequent days of the latest training sessions (at the end of the sixth week) by the physiotherapists.

Balance outcomes included the Four-Square Step Test (FSST), Functional Reach Test (FRT), Timed Up and Go Test (TUG), Timed Up and Go dual-task (TUG-cog), and Limits of Stability (LOS) test measured on NeuroCom Basic Balance Master. The desktop configuration of this device uses a fixed dual-force plate to measure the vertical forces exerted through the subject's feet to CoG and postural control.

In performing the FSST, stepping over a cane clockwise and counter-clockwise in a certain time needs moving forward, backward, and sideways[74].

During the recording of the FRT, participants have to reach in the forward direction as far as it is possible from a stable, standing position, without stepping out of the baseline position[75].

As for the TUG test, subjects have to get up from a chair, walk around an object 3 m away from the starting position, get back to the chair, and sit down[76]. The same is required in the TUG-cog, in which a cognitive task is added[77]. Both tests measure the time needed to perform the instructions.

During the LOS test, participants were required to stand on a force platform with their arms at their sides to the trunk and while watching a computer monitor, subjects were cued to move the humanoid toward the target, the representation of their CoG in eight directions (i.e., forward, forward-right, right, backward-right, backward, backward-left, left, and forward-left) within a given time[78].

Reaction time (LOS-RT) and movement velocity (LOS-V) were measured. The average of three trials of distance (FRT), time (FSST, TUG, TUG-cog, LOS-RT), and velocity (LOS-V) was used.

3.8 The applied measurements in the Kinect exergaming usability study

In general, in order to assess an individual's ability to both integrate various senses of balance and compensation, while 1 or more of these senses may be lacking[59], NeuroCom Balance Master 6.0 and the m-CTSIB[93-95] were used. The posturography measurements were performed at 3 separate intervals: before the first training, after the completion of the training program (post-training), and 6 weeks after the last training session (follow-up). The Balance Master 6.0's software provided the location of both the CoG and center of pressure across all tests for the m-CTSIB. The m-CTSIB test was initially developed by Shumway-Cook and Horak[12] to differentiate sensory (somatosensory, visual, and vestibular) inputs involved in postural stability during a steady-state balance assessment, and it explored balance on various surface types, with and without vision, using 4 sensory conditions: (1) firm surface, eyes open; (2) firm surface, eyes closed; (3) foam surface, eyes open; and (4) foam surface, eyes closed. The results provided by the Balance Master 6.0's software package gave 3 measurements of CoG (3 × 10 s) in the anteroposterior (AP) and ML directions[96]. Based on a previous study[94] with elderly females in all 4 sensory conditions, this test had good to excellent reliability of ML (intraclass correlation coefficient 0.88–0.93) and AP path length (intraclass correlation coefficient 0.85–0.90). For the assessment of balance on the foam surface, a NeuroCom square foam balance assessment pad (size 46 × 46 × 13 cm) was used. During the assessments, the base of support was fixed, and participants stood comfortably barefooted with arms to their side and their feet next to a mark on the platform. The measurements took place in a quiet room away from distractions.

3.9 Data collection and analysis in the study of the conventional balance training versus the Kinect exergaming program

All analyses were performed using Statistica 13. Datasets were checked for normal distribution using the Kolmogorov– Smirnov test. Sample demographics (age, body mass index [BMI], gender distribution) were compared using independent-samples t-tests. Baseline differences in balance parameters between the groups (Kinect vs. conventional vs. control) were tested using one-way analysis of variance (ANOVA).

Effectiveness of the different trainings on balance parameters measured by FSST, FRT, TUG and TUGcog, LOS-RT, and LOS-V was tested using two-factor mixed ANOVA with time (pre vs. post) as the within-subjects factor, and group (Kinect vs. conventional vs. control) entered as the between-subjects factor. All values are given as mean – standard deviation. The post hoc test was the Newman–Keuls test. A value of $p<0.05$ was taken as a significant training effect, and $p<0.10$ was interpreted as a statistical trend.

3.10 Data collection and analysis in the Kinect exergaming usability study

The following equations were applied to calculate the sway paths in the ML and AP directions

$$s_x = \sum_{i=1}^{n-1} \sqrt{(x_{i+1} - x_i)^2}$$

$$s_y = \sum_{i=1}^{n-1} \sqrt{(y_{i+1} - y_i)^2}$$

where n is the total number of samples; i is the sample number; s_x is the path length of ML ways; and s_y is the path length of the AP displacements of CoG. The following statistical analysis was conducted using Statistica 13 software (StatSoft). All sets of data were checked for normal distribution using the Kolmogorov–Smirnov test. Factorial analysis of variance was used to analyze sway data of the m-CTSIB test on firm and unstable (foam) surfaces to evaluate the main effects and the influences of the 2 visual conditions (eyes open and eyes closed) at all 3 time conditions (baseline, after the training, follow-up) as within-subjects factors. All values are given as mean (SD). The post hoc test was the Newman–Keuls test. A level of significance of $p<0.05$ was applied.

4. RESULTS

4.1 Results supporting hypothesis I.

4.1.1 Effects of trainings on functional performance balance tests

At baseline evaluation of the functional performance balance tests, there were no significant differences between the three groups. Our results showed a significant interaction of time group for the parameters of FSST ($F(2,146) = 4.37$, $p<0.05$) and FRT ($F(2,146) = 3.65$, $p<0.05$). The results of FSST and FRT (Figure 1.) compared with the baseline in the conventional training group and in the control group remained unchanged, while these values decreased significantly in the Kinect training group.

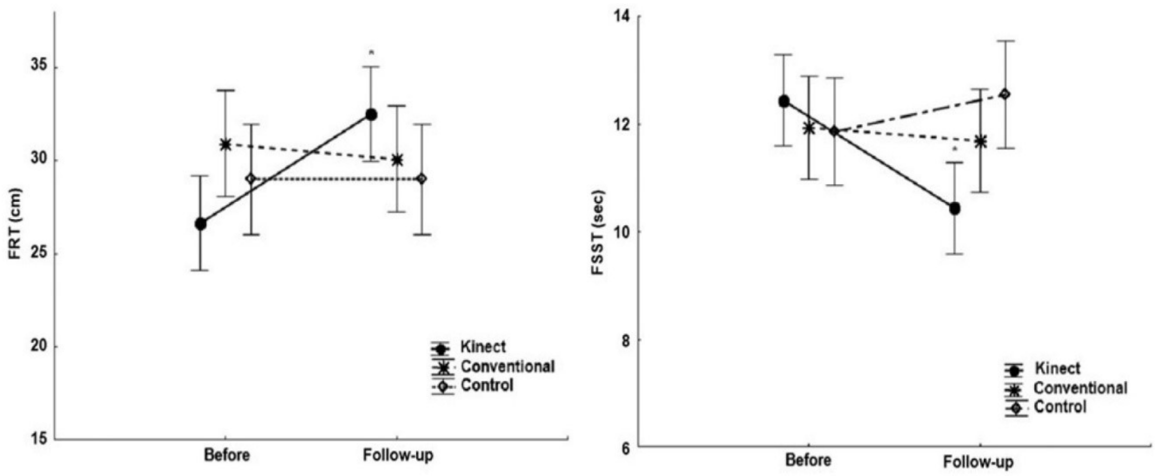

Figure 1. The effect of the three types of intervention on postural control. The time of FSST (mean – SD) before and after the different training programs. A statistically significant difference ($p<0.05$) in comparison with the preintervention data (asterisk). The distance data of FRT (mean – SD) before and after the different training programs. A statistically significant difference ($p<0.05$) in comparison with the preintervention data (asterisk). FRT, Functional Reach Test; FSST, Four-Square Step Test; SD, standard deviation.

We observed significant interaction time group for the parameter of TUG, there was a significant difference among the three experimental groups ($F(2,146) = 3.46$, $p<0.05$). Time needed for the execution of the TUG test showed significant improvement in both the Kinect training group ($p<0.05$) and in the conventional balance training group ($p<0.05$) compared with the follow-up data of the control group.

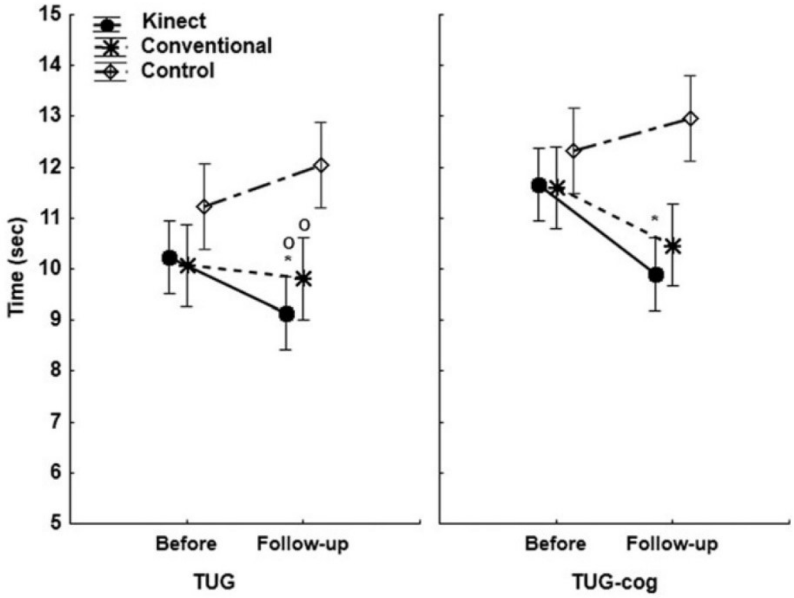

Figure 2. The effect of the three types of intervention on postural control. The time data of TUG and TUG-cog test (mean – SD) before and after the different training programs. Statistically significant differences ($p<0.05$) in comparison with the control (circle) and statistically significant differences ($p<0.05$) in comparison with the preintervention data (asterisk). TUG, Timed Up and Go Test; TUG-cog, Timed Up and Go dual-task.

While both training groups showed improvements in the TUG test, we detected a significant decrease of the time of TUG ($p<0.05$) performance after the training compared with the baseline in the Kinect group only (Figure 2).

The control group displayed nonsignificant deterioration during the 6-week period. The time needed for the test with an additional cognitive task (TUG-cog) increased in all groups before the training, although this change was not significant, just a statistical trend ($p<0.10$). However, after the training programs, the effect of the additional cognitive task showed no deterioration in the results of both intervention groups ($p>0.10$). Mixed ANOVA revealed significant interaction time group for the parameter of TUG-cog ($F(2,146) = 3.48$, $p<0.05$). The time of TUG-cog presentation decreased in both intervention groups, but this change was significant only after the Kinect training compared with the baseline data ($p<0.05$) (Figure 2).

4.1.2 Effects of training on computerized posturography test

Baseline and follow-up levels of the training groups and the control group are summarized in Table 2. There were no significant differences between the three groups at baseline evaluation. LOS-RT showed a significant training effect (time group interaction, $F(2,146) = 6.75$, $p<0.05$).

Reaction time increased in the control group, while this value in the Kinect training group slightly decreased. We observed significant changes with respect to the LOS-V test (time group interaction, $F(2,146) = 5.02$, $p<0.05$). Both the Kinect ($p<0.05$) and the conventional balance training group ($p<0.05$) significantly increased the velocity of LOS performance compared with the control group data, although only in the Kinect group was the movement velocity significantly higher ($p<0.05$) after than before the training.

Table 2. Effects of the 6-Week Training Program on Computerized Posturography Test

Parameter	*Group*	*Pre (mean ± SD)*	*Post (mean ± SD)*	*Time × group interaction,* P
Limit of stability test Reaction time (s)	Kinect (n = 30)	1.04 ± 0.63	0.89 ± 0.54	0.001
	Conventional (n = 23)	0.94 ± 0.62	1.00 ± 0.50	
	Control (n = 22)	0.91 ± 0.51	1.04 ± 0.62	
Limit of stability test Velocity (m/s)	Kinect (n = 30)	3.09 ± 1.38	3.84 ± 1.84	0.007
	Conventional (n = 23)	3.55 ± 1.61	3.77 ± 4.38	
	Control (n = 22)	3.05 ± 1.59	2.82 ± 1.15	

P values refer to the level of significance of the time group interaction of two-factor mixed ANOVA with time (pre vs. post) as within-subjects factor and group (Kinect vs. conventional vs. control) entered as the between-subjects factor.
ANOVA, analysis of variance; SD, standard deviation.

4.2 Results supporting hypothesis II. and hypothesis III.

4.2.1 Changes in Sway Path During Quiet Stance in the ML Direction

In the ML direction, the Kinect exergame training caused a significant decrease in the sway path on the firm surface with eyes open ($p<0.001$) and eyes closed ($p=0.001$), and on the foam surface with eyes open ($p=0.001$) and eyes closed ($p<0.001$) conditions compared with the baseline data. The follow-up measurements when compared with the baseline data also showed significant change in the sway path on the firm surface with eyes open ($p<0.001$) and eyes closed ($p<0.001$), and on the foam surface with eyes open ($p=0.003$) and eyes closed ($p<0.001$; Figures 3 and 4). There were no significant differences in sway path values on the firm surface between eyes open and eyes closed conditions during the baseline ($p=0.81$), after the training ($p=0.30$), and follow-up ($p=0.48$) evaluations. However, on the foam surface, results showed a significant interaction of vision × time for the sway path ($F_{2,246}=3.70$, $p=0.02$). Before the training, the sway path on the foam (unstable) surface with eyes closed was significantly longer ($p<0.001$), whereas after the training the absence of visual information did not result in a significant increase ($p=0.16$) of the sway path (Figure 4).

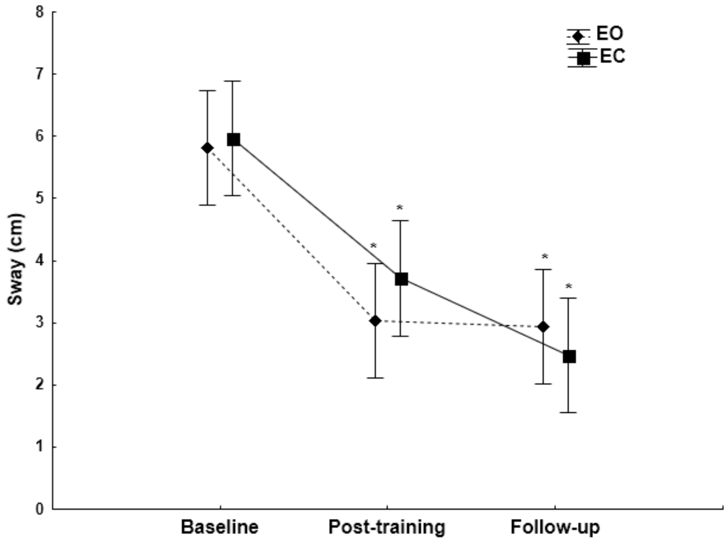

Figure 3. The effect of the Kinect training on sway path (mean [SD]) in the ML direction when standing on the firm surface with open and closed eyes. Statistically significant differences in sway path with eyes open ($p<0.001$) and eyes closed ($p=0.001$) post-training conditions compared with the baseline data (asterisk). The follow-up measurements when compared with the baseline data showed statistically significant change in sway path on the firm surface with eyes open ($p<0.001$) and eyes closed ($p<0.001$) (asterisk). ML: mediolateral.

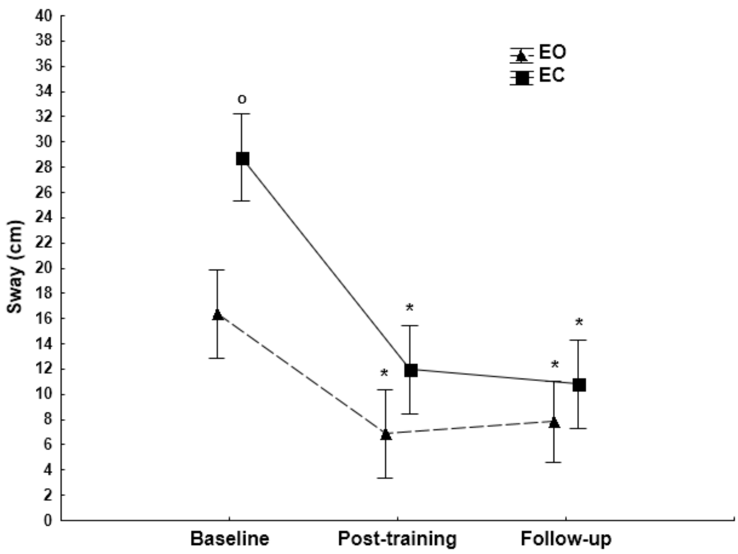

Figure 4. The effect of the Kinect training on sway path (mean [SD]) in the ML direction when standing on the foam surface with open and closed eyes. Statistically significant differences in sway path with eyes open ($p=0.001$) and eyes closed ($p<0.001$) post-training conditions compared with the baseline data. The follow-up measurements when compared with the baseline data showed statistically significant changes in sway path with eyes open ($p=0.003$) and eyes closed ($p<0.001$) (asterisk) Statistically significant difference in sway path during baseline measurements with eyes closed ($p<0.001$) compared with the eyes open condition (circle). ML: mediolateral.

4.2.2 Changes in sway path during quiet stance in the AP direction

On the firm surface, there were no significant differences in sway path values in the AP direction between the baseline and the post-training measurements (Figure 5; eyes open: p=0.49; eyes closed: p=0.18). Likewise, on the foam surface, there were no significant differences in sway path values in the AP direction under both eyes open (p=0.24) and eyes closed (p=0.84) conditions. During follow-up measurements, a main effect of vision was noted; in other words, closing the eyes resulted in a significant increase of the sway path (p<0.001; Figure 5). On the unstable foam surface, a main effect of vision was observed and the absence of visual information significantly increased (p<0.001) the sway path length in all time conditions (Figure 6).

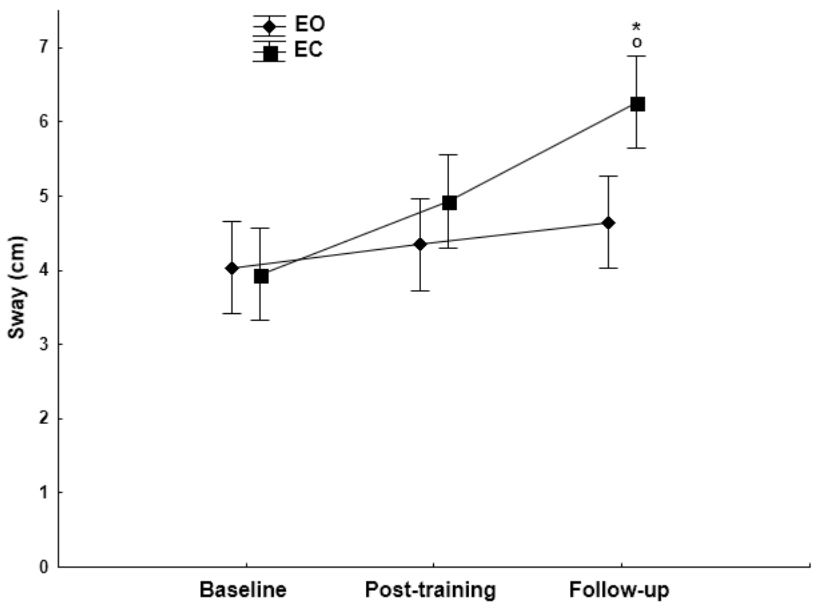

Figure 5. The effect of the Kinect training on sway path (mean [SD]) in the AP direction when standing on the firm surface with open and closed eyes. No statistically significant differences in sway path values on the firm surface between the baseline and post-training measurements (eyes open [p=0.49] and eyes closed [p=0.18]). Statistically significant differences (p<0.001) in comparison with the baseline measurement (asterisk) and in comparison with the open eye condition (circle) (p<0.001). AP: anteroposterior.

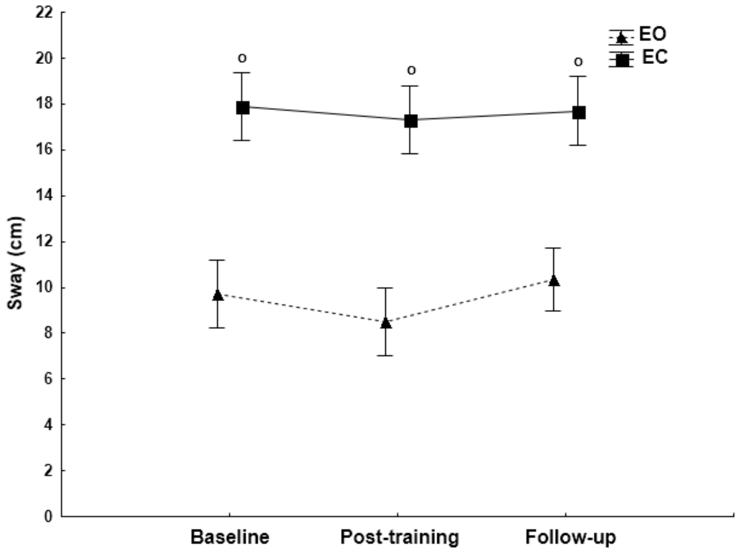

Figure 6. The effect of the Kinect training on sway path (mean [SD]) in the AP direction when standing on the foam surface with open and closed eyes. Statistically significant differences ($p<0.001$) in comparison with the open eye condition (circle). AP: anteroposterior.

5. DISCUSSION

5.1. The study of the conventional balance training versus the Kinect exergaming program

The objective of our initial study was to confirm our hypothesis that Kinect training using commercially available games can be more effective than a conventional balance training focusing on improving balance of healthy older adults. According to our results, both training groups' balance tests improved with superiority of the Kinect training group, whereas the control group remained unchanged.

5.1.1 Effects on functional performance balance tests

To our knowledge, there is no study that applied the same balance tests to investigate the effect of an exergame balance training applying commercially available Kinect games to improve healthy older adults' balance abilities. However, Keogh et al.[79] used FSST to assess dynamic balance abilities among older adults, who practiced Nintendo Wii Sports Games. In their study, the gamer group's post-training results remained unchanged compared with the control group without training. As opposed to that, our results showed statistically significant improvement in the FSST only in the Kinect training group. The reason behind our result could be that the stepping movements in the FSST were also the basis of games participants played (i.e., 20,000 Leaks, Space Pop). On the contrary, in the study of Chen[80,] the specifically developed Kinect exergames resulted in no significant change in FSST among older people.

Bieryla[55] described that there was no statistically significant enhancement in the FRT, neither in the Kinect training group nor in the control group without intervention. In contrast to that our results suggest statistically significant improvement in the FRT in the Kinect training group, while the values of the conventional training group and the control group remained unchanged. The shorter total time of the intervention and the lower sample size can be the reason why the FRT did not show any change in Bieryla's study[55]. Meanwhile, after the developed Kinect exergame trainings among older adults of Sato et al.[81] and Chen[80] FRT showed significant improvement in the exergaming groups' post-training results, and no difference was detectable in the control group in Sato's study[81].

Based on Bieryla's[55] findings, there was no statistically significant decrease in the time scores of TUG, neither in the Kinect training group nor in the control group. In a study by Karahan et al.[62] the TUG results showed statistically significant improvement only in the Kinect training group, but no relevant decrease in time in the home exercise group. Bacha et al.[57]

investigated the effect of Kinect training and the conventional physical therapy training on the Mini Balance Evaluation System Test (Mini-BESTest), including the evaluation of the TUG, with the conclusion that both groups showed statistically significant improvement compared with their baseline results. Our scores of the TUG presented both in the Kinect and in the conventional training group statistically significant enhancement compared with the control group. Furthermore, compared with the baseline results of the TUG time scores, a statistically significant decrease was shown only in the Kinect training group.

For our study, we also applied the TUG test with an additional cognitive task resulting in increased test times in all groups. The intervention groups' post-training time scores presented enhancement, moreover, the results confirmed statistically significant improvement in the Kinect training group. To our knowledge, there is no research with a similar study design that investigated the balance tests with an added cognitive task. Bacha et al.[57] measured the effects of the two trainings (Kinect balance and conventional physical therapy) on cognition and they found significant improvement in both groups' results, although for the assessment of the postural control the authors applied the Mini-BESTest. According to Pichierri et al.[82] exergames can be considered dual-tasks since the games are performed by a man-videogame interface, requiring cognitive and motor functions simultaneously. The TUG test with an additional cognitive task is also a dual-task, and therefore, our results can confirm that the Kinect training has a major effect on performance with high cognitive and motor demands.

According to Monteiro-Junior et al.[83] during exergames, participants move in a simulated virtual environment, where they need to perform random, constantly changing elements (open task). Kinect training can provide open tasks, and they may improve cognitive functions, since individuals need to understand and interact with a virtual environment context. Physical exercise and cognitive stimulation performed together show the potential that exergames may provide a new strategy to stimulate neuroplasticity and improve cognitive functions[83]. As a result of exergaming containing anticipated visual tasks in a virtual environment, cognitive processing, and movements concurrently, therefore it might provide the possibility of training visuomotor integration.

5.1.2 Effect on posturography tests

We have not found any study so far that has been conducted on improving postural control through conventional and Kinect balance training in older adults that applied NeuroCom Basic Balance Master for the evaluation of LOS. As stated by Bourelle et al.[84] the LOS test is associated with cognitive functionality, and they found that this evaluates motor and cognitive capabilities to respond to the complex task of initiating a movement with certain accuracy, in function of a visual stimulus. Faraldo-Garcia et al.[85] concluded that aging affects the reaction time, the movement velocity of the LOS performance. During the LOS test, we found that both interventions enhanced the reaction time and the summed velocity compared with the follow-up results of the control group. Moreover, the post-training results of the Kinect training compared with its baseline improved significantly.

The central nervous system regulates movements and stability by using two main postural strategies to maintain (proactive) and to restore (reactive) postural control[86]. In older adults preparing for an external, predictable perturbation, anticipatory postural adjustments (APAs) and compensatory postural adjustments (CPAs) to restore balance are significantly delayed[87]. Furthermore, impairment in visual and cognitive function can also be detected due to aging resulting in the enhanced risk of falls[88]. APAs can be considered the first line of defense against falling, followed by CPAs, and both play an important role in maintaining balance[86]. To our knowledge, there is no functional balance test or posturography test for the direct evaluation of APAs. Whereas Hwang et al.[89] found correlation between the APAs measured with Electromyography and the TUG and the TUG cognitive tests. Findings by Bacha et al.[57] suggest that both conventional physical therapy and Kinect training enhance APAs, and therefore, due to our results of the TUG and TUGcog we suspect that Kinect training intervention might have more effect on APAs than the conventional balance training.

5.2 The Kinect exergaming usability study

Several studies have previously confirmed the beneficial effects of exergames on postural control among older adults[55, 57-60, 63, 97-99]. This usability study shows that a simple Kinect game–based balance training might be beneficial for older women by improving balance in the ML direction. This study also demonstrates that exergaming might have a favorable effect in regards to the specific process of adjusting the sensory contributions to balance control[100], namely, sensory reweighting.

5.2.1 Increased lateral stability

Based on our study results, an important finding is that the sway path in the ML direction on firm and foam surfaces, with eyes open and closed, improved statistically significantly, whereas no significant change was detected in the AP direction. However, decreased sway path indicates improved stability in the ML direction, which was concluded by Qazi et al.[43] as the strongest component of postural sway predicting fractures in postmenopausal women.

According to previous studies in the elderly population[101-103], ML sway can often be associated with the risk of falls due to decreased proprioception and lower extremity muscle weakness in the lateral direction[104]. In light of the present findings following the training, improved sway results in the ML direction were observed when participants were standing on the foam surface with their eyes open. The significant decrease of ML sway might also implicate an improvement in proprioceptive function following the Kinect training. This finding is similar to the results of Sadeghi et al.[105], which suggest that Kinect exergaming can improve proprioception by providing visual feedback and challenging motor skills and visual coordination.

5.2.2 Improvement in sensory reweighting

An important finding of this paper is that the Kinect exergame training program significantly reduced postural sway on the foam surface with the eyes closed. Under this condition of the m-CTSIB, the central nervous system mostly relies on vestibular information[12]. In the review by Tahmosybayat et al.[106], no exergame study has been presented that would train and assess sensory integration and sensory reweighting. Moreover, the authors suggested that the elements of sensory integration are too unsafe to be trained by disturbed sensory inputs during exergames. However, Roopchand-Martin et al.[67] have examined the changes in m-CTSIB results following the Nintendo Wii Fit balance training in community-dwelling adults aged over 60. They found no significant results on the foam surface with the eyes closed condition after the training. By contrast, a Kinect-based physical exercise balance intervention in women with fibromyalgia has revealed significant improvements in the m-CTSIB with eyes closed on foam surfaces[68]. Another study that examined the Wii Fit balance training for healthy women also found similar results: significant sensorimotor improvement in unilateral stance and limb strength[69]. Nitz et al. concluded that these findings might not be surprising because the activities included in the Wii Fit training (such as yoga, balance, aerobic, and strength activities) involved considerable single-limb balance requirements and body weight–resistance movements[69]. Although the aforementioned studies[68-69] investigated the effects of exergaming on balance in various sensory conditions with m-CTSIB, sensory reweighting following the trainings has not been proposed in these papers.

In contrast to these results, Yen et al.[64] demonstrated that VR balance training significantly improved sensory reweighting in older adults with Parkinson's disease when both visual and somatosensory inputs were unreliable. They have suggested that the VR training might be especially beneficial for fall prevention within this high-risk target group, as similar conditions may also occur in reality due to various extrinsic environmental risk factors (inappropriate footwear, poor lighting, slippery surfaces, loose rugs, or uneven steps)[64]. Other studies have found significant improvement in the eyes closed condition on the unstable surface following a Wii Fit balance training among young adults[65] and healthy adults[66]. According to these studies[65-66], the reason for the improved vestibular function might be due to the quick displacement of CoG in different directions, causing rapid changes in the head position. Similarly, during pretest measurements in this study, closing the eyes on the foam surface resulted in a statistically significant increase in the sway scores in the ML direction; however, post-training measurements did not show deteriorated sway results. The reason for this might be that after the training, participants shifted to the remaining, accurate source of sensory information, and mainly relied on the vestibular system. Another possible explanation might be that during exergaming, participants had to complete several tasks containing movements such as reaching out and lateral steps while they needed to often change their head position.

Santos et al.[107] have suggested that VR therapy enables patients to become immersed in an imaginary world, in which environmental perception is altered by artificial stimuli, thus resulting in a sensory conflict that can act on the vestibulo-ocular reflex (VOR). The central nervous system reacts to a vestibular stimulus by reflexes such as the VOR, which stabilizes vision during head motion, and the vestibulospinal reflex, which induces a compensatory body motion to stabilize the head and body and prevent falls[108]. Thus, types of exergames that require head movements in particular (rotation, lateral flexion, flexion) while players' eyes are focusing (gazing) at one point can function as VOR training. Based on this study's results, the applied Kinect games might improve sensory reweighting in favor of relying on vestibular inputs. In this study, while participants were playing the exergames, they had to keep their eyes on the screen while performing various head and limb movements.

5.2.3 Lessons learned from Kinect exergames

Games such as 20, 000 Leaks, River Rush, Reflex Ridge, Super Saver Football mini-game, Space Pop, and Skiing might especially challenge the VOR because they require frequent head displacement movements. Additionally, these games could also improve stability in the lateral direction because of frequent weight shifting and sideward stepping. According to Swanenburg et al.[109], exergaming that requires active stepping movements and that involves moving game projection is usable and facilitates gaze stability during head movements, which resulted in improved gait in healthy older adults. As balance is determined by various factors and maintained by complex processes, designing a balance training program requires precisely defining which target components or systems ought to be trained. Health care professionals might use exergames that could display participants’ changes of postural sway, reaction time, and limit of stability in various directions. Games which can train VOR by gaze stability during head movements should be provided for continuous monitoring to track players’ head movements. As falls occur mostly during activities of everyday life, exergames should be designed to involve functional movements that represent motions from daily life: alternately raising the feet from the ground (e.g., stair-stepping, stepping out of the bathtub), or reaching movements forward and sideways (e.g., taking an item off a shelf below and above shoulder height, cleaning a window, hanging out the washing).

6. LIMITATIONS AND CONCLUSIONS

6.1 Limitations in the study of the conventional balance training versus the Kinect exergaming program

One limitation to this study is that no sample calculus has been made and gender distribution is unequal. Moreover, to set up a more precise treatment regimen with Kinect games, further research would be necessary on investigating the exact amount of time, frequency, and regularity of trainings since our aim is to provide long-lasting balance interventions. In addition, another limitation is that no further follow-up results have been performed, which could verify the lasting effects of our trainings.

6.1.1 Conclusions in the study of the conventional balance training versus the Kinect exergaming program

Several studies investigated the effects of the custom-made Kinect game training for older adults[90-92]. According to our present results, the commercially available Kinect games are able to fulfill the requirements of a functional balance training, since these games make their players to move in functional movement patterns, while participants' attention is directed to problem-solving and throughout entertaining tasks. We choose balance tests to get an objective estimation about our volunteers' postural control, which are based on movements performed in everyday life and the games, players played. For this reason, Kinect game training is a suitable tool for training postural control of healthy older adults.

6.2. Limitations of the Kinect exergaming usability study

This usability study has encountered certain limitations as no sample size calculation was performed, and due to the lack of a control group and the relatively small sample size, the results should be interpreted cautiously. Therefore, these findings are not conclusive. Recruiting volunteers via local paper announcements for exergaming was not sufficient to get the attention we had hoped for. We believe that to attract more participants for future balance training programs, other types of advertisements should be used to generate interest. Posts on social media with video demonstrations and trials could raise interest especially among the youth, who could encourage their older relatives to participate. In this study, only older women participated, but to examine whether there is a gender difference in sensory reweighting following exergaming, future studies should also include a group of male participants. Investigating the effects of exergaming in older individuals with vestibular dysfunctions could also be beneficial, as this population is especially at risk of falling. Although there are studies that have described the positive effects of exergaming on balance ability[110-111] and on higher-order cognitive functions[112] when training independently at home, this study could not have been performed using a home-based exergame program. The reason for that is that the applied commercially available Kinect games are in English and no Hungarian translation is available. Therefore, participants needed assistance with starting and setting up the games, as well as technical help.

6.2.1 Conclusions of the Kinect exergaming usability study

In this usability study, women's sway path decreased in the ML direction not only on the firm surface with eyes open, but also on the foam surface with eyes closed as a result of following the Kinect exergame training. These findings might support the idea that although the Kinect exergame training did not specifically contain direct challenging sensory tasks (e.g., tilting or unstable surface or closed eyes exercises), the reduced sway results suggest that exergames could additionally result in sensory reweighting. The reason for this might be that the games contained tasks that needed constant gaze stabilizing and frequent head displacements. Therefore, this study's improved sway results in the ML direction might contribute to decreased risk of falls among older women.

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I.

Is Kinect Training Superior to Conventional Balance Training for Healthy Older Adults to Improve Postural Control?

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Abstract

Objective: To investigate the effects of balance training to improve postural control in adults older than 60. Our aim was to find out if Kinect training is superior to the conventional balance training in aspects of functional balance tests and posturography measurements testing postural stability through visual feedback.
Materials and Methods: Thirty subjects participated in the Kinect training group (29 women and 1 man), practiced Kinect Adventures and Sports, 23 volunteers (22 women and 1 man) attended the conventional balance training, and 22 participants (18 women and 4 men) were allocated to the no-intervention control group. Both interventions lasted for 6 weeks, three times a week, and 30 minutes per session. The Four-Square Step Test, Functional Reach Test, Timed Up and Go test, Timed Up and Go cognitive dual-task test were measured, and for the assessment of the limit of stability (LOS), we used computerized posturography. Measurements were taken before the training at baseline and 6 weeks after (follow-up) the interventions. Statistical analysis was done through two-factor mixed analysis of variance and Newman–Keuls post hoc test.
Results: Both training groups showed progress in the follow-up measurements; however, more statistically significant improvements were found in favor of the Kinect balance training group (Timed Up and Go test [$P<0.05$], Timed Up and Go cognitive dual-task test [$P<0.05$], Four-Square Step Test [$P<0.05$], Functional Reach Test [$P<0.05$], LOS movement velocity [$P<0.05$]).
Conclusion: Our results suggest that Kinect balance training may be a preferable and safe method for the healthy older adults to improve postural control and reduce the possibility of falling.

Keywords: Virtual reality, Aged, Physical therapy modalities, Postural balance

Introduction

Living surrounded with 21st century technology in a fast-paced, rapidly changing computerized world and environment, even our instinctively trusted balance abilities are unsteady. Balance impairments among older populations resulting serious adverse effects such as falls are well known in geriatrics. According to the Institute of Health Metrics and Evaluation,[1] the fifth cause of death and disability was falls in Hungary, where among 100,000 people, 1045 citizens suffered injury or died due to falls. Therefore, early morbidity, immobility, premature nursing home placement, or surgical interventions are serious conditions that older adults deal with.

The reason for decreased balance abilities is often multifactorial; meaning that it is difficult to determine only one exact cause of balance dysfunctions.[2] Previous literature[3] indicates that with increased age, components of the neuromuscular, sensory, and cognitive systems, which are the main constituents for the appropriately functioning balance, become decreased. Moreover, balance is also influenced by constantly changing factors such as the environment (poor lightning, crowded spaces, and slippery support surface) or the individual's emotional and general physical status.[4] Deficiency of any of these components may remain undetected until the first experience of a fall. Therefore, to reduce the effects of age-related changes on balance, choosing a training method that improves all levels of the impaired balance is essential.

For the prevention and delay of serious consequences of falls due to postural control impairments in older age, there

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have been several attempts in physiotherapy during the last decades. Various studies confirmed that physical exercise training,[5] aquatic gymnastics,[6] strength training,[7] and Tai Chi[8] are effective balance enhancement methods designed for older adults. Furthermore, according to Rogge et al.,[9] balance training and physical exercising[10] can develop older adults' cognitive functions as well.

Dual tasking is frequent in daily life. Maki et al.[11] described that neural structure theories propose that dual-task interference effects appear since there are competing demands for specific neural pathways within the brain. Exergames can also be considered dual task, in which subjects have to perform two tasks via cognitive and motor performances[12] simultaneously, which is beneficial for training postural control.

When active videogame devices were released shortly, they gained popularity in balance rehabilitation too, although these products primarily did not serve any therapeutic purpose. In a review by Kinne et al.,[13] several studies had compared the effects of Nintendo® Wii™ games with conventional balance exercising among healthy older adults. Commercially available Kinect games contain whole-body movements based on visual feedback in a realistic virtual environment, and therefore, they may improve physical and cognitive parts of postural control as well. Another advantage of Kinect gaming is that players do not need any handheld controller to practice sporting activities and their basic movements such as ski, tennis, and football, and that experiencing these sports can become realistic via visual feedbacks in a virtual environment compared with a conventional training. In addition to that, Kinect games are operating with rewarding mechanisms; players are given reward points to motivate them during the games.

Only few studies investigated the effects of commercially available Kinect gaming training either versus an exercise training or a conventional physical therapy or a no-intervention control group on balance improvement in the same target population.[14–16]

To our knowledge, this is the first article that compares the effects of these different types of training groups at the same time in healthy older adults focusing on only the functional balance tests completed with posturography measurement testing postural stability through visual feedback. To investigate if the Kinect training program is more effective than the conventional balance training, it is essential to apply various balance tests that represent balance abilities of everyday life movements or body movement patterns. Therefore, the aim of our study was to confirm that the Kinect training using commercially available games might be more prominent than conventional balance training on improving functional balance of healthy older adults.

Methods

Participants

Healthy community-dwelling older adults (free from known musculoskeletal, neurological, and cardiopulmonary disorders), older than 60, were recruited ($n = 117$) (Fig. 1) for our study on improving balance abilities through local announcements in senior centers of the city Szeged, Hungary. Exclusion criteria included self-reported cognitive impairment, disorders of the heart and circulatory system, musculoskeletal, respiratory, and autoimmune diseases, neurological conditions, hearing or vision loss, artificial limbs or prosthetics, sores on lower limbs or feet or corns, and taking medication that could affect the postural control. On the arrival of subjects (on a first-come, first-served basis), participants were enrolled to the Kinect training group or the conventional balance training group or to the no-intervention control group. Subjects were kept unaware about the method of allocation and about different types of groups, but the authors were not blinded to the group assignment. Our volunteers were informed about the start and procedure of the study one by one.

Our participants performed casual daily activities but did not participate in any organized physical training exercise program. To avoid any bias, for the duration of our study we asked our participants not to be engaged parallel in any other structured physical exercise or balance training program. The Ethics Committee of the University of Szeged, Hungary, approved the study (registration no. 125/2015 SZTE). A signed informed consent was obtained from all individuals before their participation in the research. All procedures were performed according to the Declaration of Helsinki. Our study ran between July and November 2015.

Intervention

The Kinect training group. Prior the study, the participants did not have any experience with exergames, thus before the very first training, the group was given an introductory demonstration on how to play the gesture-controlled videogames. Subjects were trained with the Microsoft Xbox 360 Kinect (Redmond, WA) videogames. Kinect is a motion-sensing input device produced by Microsoft for Xbox 360 videogame consoles and is based around an RGB camera, providing among others full-body 3D motion capture. The pictures of the game were projected on the wall, and with the help of the Kinect sensor. Before the training, we conducted a pilot testing exergaming session where subjects were grouped into matched pairs based on age, physical abilities, understanding the tasks in the virtual environment, and summed points reached in the pilot gaming session.

Subjects participated in the training sessions three times a week for 6 weeks (altogether 18 times), conducted by physiotherapists. Each training session took 30 minutes for each of the participants. During the 30-minute activity, there was ~1-minute transition time between the games, when players could take a rest. Games that require more predictable movements and more simple elements (e.g., bowling or football, skiing, and just dance) were played in half of the total game time and those games that necessitate higher attention and fast reaction times (20.000 Leaks, Space Pop, Reflex Ridge, River Rush) were chosen to play for the second half of one training session. Participants played the same type of games in the same order on each gaming day to avoid bias. Relying on the methods of previous studies[14,17,18] that effectively used Kinect games for rehabilitation or improving balance in our research, we applied games that also contain patterns of everyday functional movements, which model usual natural motions, that is, reaching and leaning toward something, upper limb movements while static standing, weight shifting, forward, backward, and side stepping, squatting, lunging, and hopping. Players' adaptation and progression

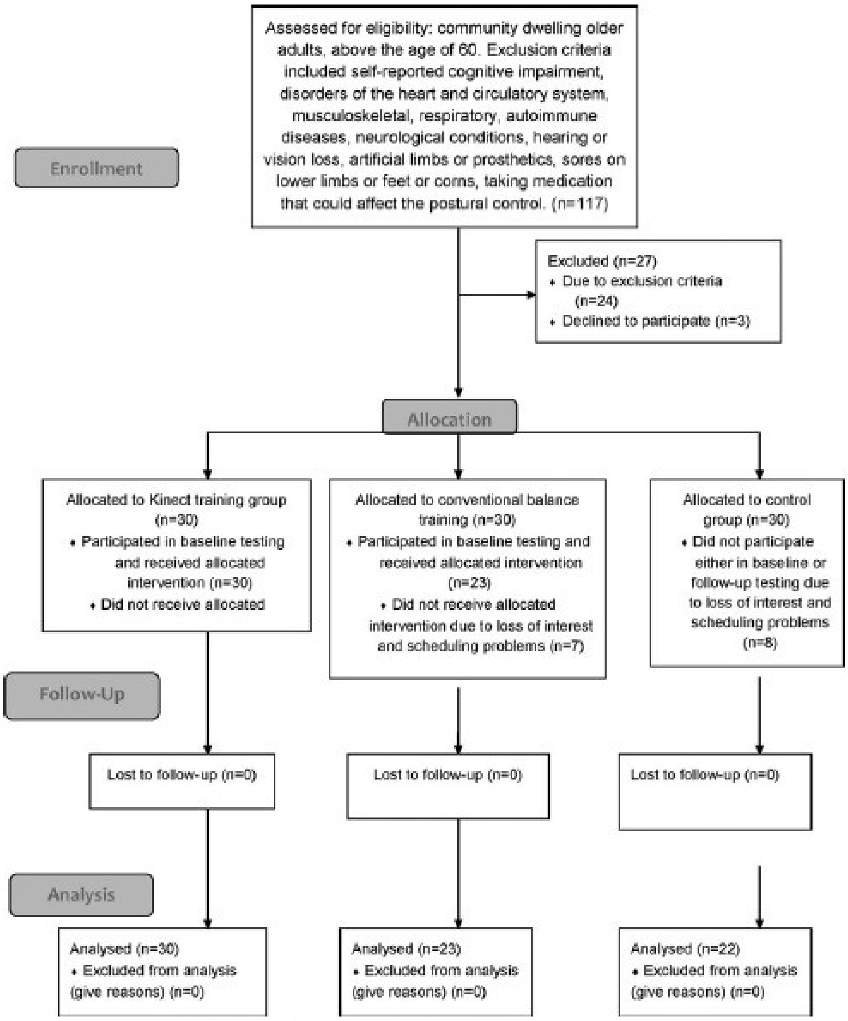

FIG. 1. Flow chart of participant's allocation process.

were also considered, and therefore, the level of difficulty of the games was continuously set during the training.

Conventional balance training group. Before the training, we conducted a pilot testing balance training session where subjects were grouped into matched pairs based on age, physical abilities, and understanding the exercises. Participants who performed conventional balance training were trained for 6 weeks, three times a week (altogether 18 trainings). During the interventions, volunteers were instructed by a physiotherapist on how to complete the exercises. The balance training was performed in an exercise room at a clinical physiotherapy department. On the basis of the studies of Zhuang et al.[19] and Halvarsson et al.,[20] our training targeted balance control in specific situations that can occur in daily life, such as obstacle course, applying cognitive tasks with simultaneously performed physical exercises. On the abovementioned methods of researches,[19,20] our training consisted of three parts: the first few minutes of the training session contained light warm-up exercises (arm, leg and neck movements, marching in place) followed by the main part of the training, where participants performed static and dynamic balance exercises that also included reaching and leaning, weight shifting, forward, backward, and side stepping, change of direction exercises, squatting, lunging, and hopping tasks. The sessions ended with a few minutes lasting cool-down part, including stretching and breathing exercises.

Control group. Members of the control group received no balance training, only pre- and postmeasurements (in 6 weeks).

Outcome measures

The outcome measures were recorded before the training (at baseline) and at the subsequent days of the latest training sessions (at the end of the sixth week) by the physiotherapists. Balance outcomes included Four-Square Step Test (FSST), Functional Reach Test (FRT), Timed Up and Go Test (TUG), Timed Up and Go dual-task (TUG-cog), and Limits of Stability (LOS) test measured on NeuroCom Basic Balance Master®. The desktop configuration of this device uses a fixed dual-force plate to measure the vertical forces exerted through the subject's feet to measure center of gravity (COG) and postural control.

In performing the FSST, stepping over a cane clockwise and counter clockwise in a certain time needs moving forward, backward, and sideways.[21] During the recording of the FRT, participants have to reach in forward direction as far as it is possible from a stable, standing position, without stepping out of the baseline position.[22] As for the TUG test, subjects have to get up from a chair, walk around an object 3 m away from the starting position, get back to the chair, and sit down.[23] The same is required in the TUG-cog, in which a cognitive task is added.[24] Both tests measure the time needed to perform the instructions. During the LOS test, participants were required to stand on a force platform with their arms at their sides to the trunk and while watching a computer monitor, subjects were cued to move the humanoid toward the target, the representation of their COG in eight directions (i.e., forward, forward-right, right, backward-right, backward, backward-left, left, and forward-left) within a given time.[25] Reaction time (LOS-RT) and movement velocity (LOS-V) were measured.

The average of three trials of distance (FRT), of time (FSST, TUG, TUG-cog, LOS-RT), and of velocity (LOS-V) was used.

Data analysis

All analyses were performed using Statistica 13. Datasets were checked for normal distribution using the Kolmogorov–Smirnov test. Sample demographics (age, body mass index [BMI], gender distribution) were compared using independent-samples t-tests. Baseline differences in balance parameters between the groups (Kinect vs. conventional vs. control) were tested using one-way analysis of variance (ANOVA). Effectiveness of the different trainings on balance parameters measured by FSST, FRT, TUG and TUG-cog, LOS-RT, and LOS-V was tested using two-factor mixed ANOVA with time (pre vs. post) as the within-subjects factor, and group (Kinect vs. conventional vs. control) entered as the between-subjects factor. All values are given as mean ± standard deviation. The post hoc test was the Newman–Keuls test. A value of $P < 0.05$ was taken as a significant training effect, and $P < 0.10$ was interpreted as a statistical trend.

Results

Altogether 75 subjects participated in our study (Fig. 1), without any dropouts.

Demographic data

The demographic characteristics of participants in the three groups are presented in Table 1. There were no significant differences between the training and control groups in age, sex distribution, and BMI ($P < 0.05$).

Effects of training on functional performance balance tests

At baseline evaluation of the functional performance balance tests, there were no significant differences between the three groups.

Our results showed a significant interaction of time × group for the parameters of FSST ($F(2,146) = 4.37$, $P < 0.05$) and FRT ($F(2,146) = 3.65$, $P < 0.05$). The results of FSST and FRT (Fig. 2) compared with the baseline in the conventional training group and in the control group remained unchanged, while these values decreased significantly in the Kinect training group.

We observed significant interaction time × group for the parameter of TUG, there was a significant difference among the three experimental groups ($F(2,146) = 3.46$, $P < 0.05$). Time needed for the execution of the TUG test showed significant improvement in both the Kinect training group ($P < 0.05$) and in the conventional balance training group ($P < 0.05$) compared with the follow-up data of the control group. While both training groups showed improvements in TUG test, we detected a significant decrease of the time of TUG ($P < 0.05$) performance after the training compared with the baseline in the Kinect group only (Fig. 3). The control group displayed nonsignificant deterioration during the 6-week period.

The time needed for the test with an additional cognitive task (TUG-cog) increased in all groups before the training, although this change was not significant, just a statistical trend ($P < 0.10$). However, after the training programs, the effect of the additional cognitive task showed no deterioration in the results of both intervention groups ($P > 0.10$).

Mixed ANOVA revealed significant interaction time × group for the parameter of TUG-cog ($F(2,146) = 3.48$, $P < 0.05$). The time of TUG-cog presentation decreased in both intervention groups, but this change was significant only

TABLE 1. DEMOGRAPHIC DATA OF THE GROUPS

	Kinect balance training group	*Conventional balance training group*	*Control group*	P
N	30	23	22	>0.05
Age (years)	69.57 ± 4.66	69.12 ± 4.19	67.18 ± 5.56	>0.05
Sex distribution (male/female)	1/29	1/23	4/18	>0.05
BMI (kg/m^2)	26.21 ± 2.60	25.95 ± 2.60	27.09 ± 5.45	>0.05

BMI, body mass index.

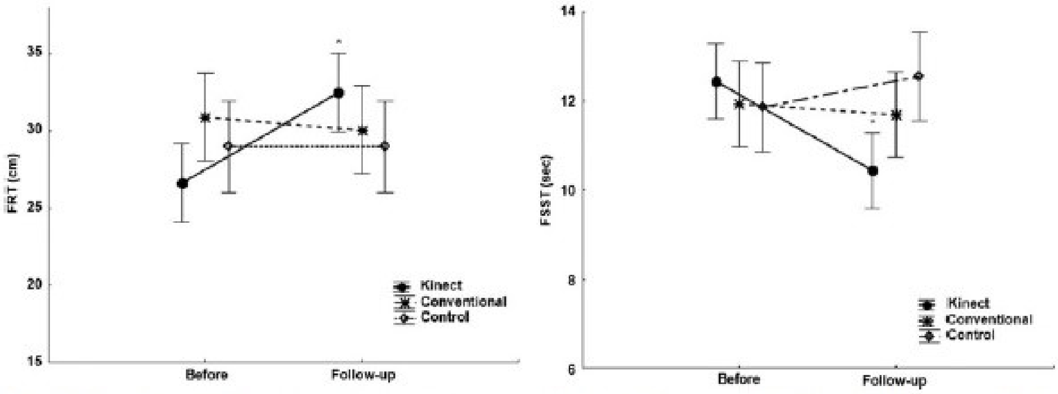

FIG. 2. The effect of the three types of intervention on postural control. The time of FSST (mean ± SD) before and after the different training programs. Statistically significant difference ($P < 0.05$) in comparison with the preintervention data (asterisk). The distance data of FRT (mean ± SD) before and after the different training programs. Statistically significant difference ($P < 0.05$) in comparison with the preintervention data (asterisk). FRT, Functional Reach Test; FSST, Four-Square Step Test; SD, standard deviation.

after the Kinect training compared with the baseline data ($P < 0.05$) (Fig. 3).

Effects of training on computerized posturography test

Baseline and follow-up levels of the training groups and the control group are summarized in Table 2. There were no significant differences between the three groups at baseline evaluation.

LOS-RT showed a significant training effect (time × group interaction, $F(2,146) = 6.75$, $P < 0.05$). Reaction time increased in the control group, while this value in the Kinect training group slightly decreased.

We observed significant changes with respect to LOS-V test (time × group interaction, $F(2,146) = 5.02$, $P < 0.05$). Both the Kinect ($P < 0.05$) and the conventional balance training group ($P < 0.05$) significantly increased the velocity of LOS performance compared with the control group data, although only in the Kinect group was the movement velocity significantly higher ($P < 0.05$) after than before the training.

Discussion

The objective of our study was to confirm our hypothesis that Kinect training using commercially available games can

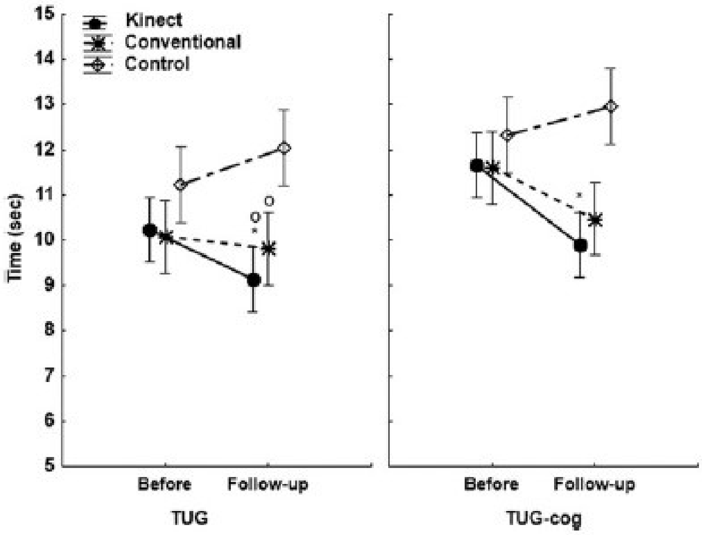

FIG. 3. The effect of the three types of intervention on postural control. The time data of TUG and TUG-cog test (mean ± SD) before and after the different training programs. Statistically significant differences ($P < 0.05$) in comparison with the control (circle) and statistically significant differences ($P < 0.05$) in comparison with the preintervention data (asterisk). TUG, Timed Up and Go Test; TUG-cog, Timed Up and Go dual-task.

TABLE 2. EFFECTS OF THE 6-WEEK TRAINING PROGRAM ON COMPUTERIZED POSTUROGRAPHY TEST

Parameter	Group	Pre (mean ± SD)	Post (mean ± SD)	Time × group interaction, P
Limit of stability test Reaction time (s)	Kinect (n = 30)	1.04 ± 0.63	0.89 ± 0.54	0.001
	Conventional (n = 23)	0.94 ± 0.62	1.00 ± 0.50	
	Control (n = 22)	0.91 ± 0.51	1.04 ± 0.62	
Limit of stability test Velocity (m/s)	Kinect (n = 30)	3.09 ± 1.38	3.84 ± 1.84	0.007
	Conventional (n = 23)	3.55 ± 1.61	3.77 ± 4.38	
	Control (n = 22)	3.05 ± 1.59	2.82 ± 1.15	

P values refer to level of significance of the time × group interaction of two-factor mixed ANOVA with time (pre vs. post) as the within-subjects factor and group (Kinect vs. conventional vs. control) entered as the between-subjects factor.
ANOVA, analysis of variance; SD, standard deviation.

be more effective than a conventional balance training focusing on improving balance of healthy older adults. According to our results, both training groups' balance tests improved with superiority of the Kinect training group, whereas the control group remained unchanged.

Effects on functional performance balance tests

To our knowledge, there is no study that applied these tests to investigate the effect of an exergame balance training applying commercially available Kinect games to improve healthy older adults' balance abilities. However, Keogh et al.[26] used FSST to assess dynamic balance abilities among older adults, who practiced Nintendo Wii Sports Games. In their study, the gamer group's post-training results remained unchanged compared with the control group without training. As opposed to that, our results showed statistically significant improvement in the FSST only in the Kinect training group. The reason behind our result could be that the stepping movements in the FSST were also the basis of games participants played (i.e., 20,000 Leaks, Space Pop). On the contrary, in the study of Chen,[27] the developed Kinect exergames showed no significant change in FSST among older people.

Bieryla[14] described that there was no statistically significant enhancement in the FRT, neither in the Kinect training group nor in the control group without intervention. In contrast with that our results suggest statistically significant improvement in the FRT in the Kinect training group, while the values of the conventional training group and the control group remained unchanged. The shorter total time of the intervention and the lower sample size can be the reason why the FRT did not show any change in Bieryla's study.[14] Meanwhile, after the developed Kinect exergame trainings among older adults of Sato et al.[28] and Chen,[27] FRT showed significant improvement in the exergaming groups' post-training results, and no difference was detectable in the control group in Sato's study.

Based on Bieryla's[14] findings, there was no statistically significant decrease in the time scores of TUG, neither in the Kinect training group nor in the control group. In a study by Karahan et al.,[15] the TUG results showed statistically significant improvement only in the Kinect training group, but no relevant decrease in time in the home exercise group. Bacha et al.[16] investigated the effect of Kinect training and the conventional physical therapy training on the Mini-BESTest, including the evaluation of the TUG, with the conclusion that both groups showed statistically significant improvement compared with their baseline results. Our scores of the TUG presented both in the Kinect and in the conventional training group statistically significant enhancement compared with the control group. Furthermore, compared with the baseline results of the TUG time scores, a statistically significant decrease was shown only in the Kinect training group.

For our study, we also applied the TUG test with an additional cognitive task resulting in increased test times in all groups. The intervention groups' post-training time scores presented enhancement, moreover, the results confirmed statistically significant improvement in the Kinect training group. To our knowledge, there is no research with similar study design that investigated the balance tests with an added cognitive task. Bacha et al.[16] measured the effects of the two trainings on cognition and they found significant improvement in both groups' results, although for the assessment of the postural control the authors applied the Mini-BESTest. According to Pichierri et al.,[12] exergames can be considered dual tasks since the games are performed by a man–videogame interface, requiring cognitive and motor functions simultaneously. The TUG test with an additional cognitive task is also a dual task, and therefore, our results can confirm that the Kinect training has a major effect on performance with high cognitive and motor demands.

According to Monteiro-Junior et al.,[29] during exergames, participants move in a simulated virtual environment, where they need to perform random, constantly changing elements (open task). Kinect training can provide open tasks, and they may improve cognitive functions, since individuals need to understand and interact with a virtual environment context. Physical exercise and cognitive stimulation performed together show the potential that exergames may provide a new strategy to stimulate neuroplasticity and improve cognitive functions.[29] As a result of exergaming containing anticipated visual tasks in a virtual environment, cognitive processing, and movements concurrently, therefore it might provide the possibility of training visuomotor integration.

Effect on posturography test

We have not found any study so far that has been conducted on improving postural control through conventional and Kinect balance training in older adults that applied NeuroCom Basic Balance Master for the evaluation of LOS. As stated by Bourelle et al.,[30] the LOS test is associated with cognitive functionality, and they found that this evaluates motor and cognitive capabilities to respond to the complex task of initiating a movement with certain accuracy, in function of a visual stimulus. Faraldo-Garcia et al.[31] concluded that aging affects the reaction time, the movement velocity of the LOS performance. During LOS test, we found that both interventions enhanced the reaction time and the summed velocity compared with the follow-up results of the control group. Moreover, post-training results of the Kinect training compared with its baseline improved significantly.

The central nervous system regulates movements and stability by using two main postural strategies to maintain (proactive) and to restore (reactive) postural control.[32] In older adults preparing for an external, predictable perturbation, anticipatory postural adjustments (APAs) and compensatory postural adjustments (CPAs) to restore balance are significantly delayed,[33] and impairment in visual and cognitive function can also be detected due to aging,[34] resulting in the enhanced risk of falls. APAs can be considered the first line of defense against falling, followed by CPAs, and both play an important role in maintaining balance.[32] To our knowledge, there is no functional balance test or posturography test for the direct evaluation of APAs. Whereas Hwang et al.[35] found correlation between the APAs measured with Electromyography and the TUG and the TUG-cognitive tests. Findings by Bacha et al.[16] suggest that both conventional physical therapy and Kinect training enhance APAs, and therefore, due to our results of the TUG and TUG-cog we suspect that Kinect training intervention might have more effect on APAs than the conventional balance training.

One limitation to this study is that no sample calculus has been made and gender distribution is unequal. Moreover, to set up a more precise treatment regimen with Kinect games, further research would be necessary on investigating the exact amount of time, frequency, and regularity of trainings since our aim is to provide long-lasting balance interventions. In addition, another limitation is that no further follow-up results have been performed, which could verify the lasting effects of our trainings.

Conclusion

Several studies investigated the effects of the custom-made Kinect game training for older adults.[36–38] According to our present results, the commercially available Kinect games are able to fulfill the requirements of a functional balance training, since these games make their players to move in functional movement patterns, while participants' attention is directed to problem solving and throughout entertaining tasks. We choose balance tests to get an objective estimation about our volunteers' postural control, which are based on movements performed in everyday life and in the games, players played. For this reason, Kinect game training is a suitable tool for training postural control of healthy older adults.

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Author Disclosure Statement

No competing financial interests exist.

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II.

Original Paper

The Effects of Exergaming on Sensory Reweighting and Mediolateral Stability of Women Aged Over 60: Usability Study

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Abstract

Background: Older adults tend to experience difficulties in switching quickly between various reliable sensory inputs, which ultimately may contribute to an increased risk of falls and injuries. Sideward falls are the most frequent cause of hip fractures among older adults. Recently, exergame programs have been confirmed as beneficial tools for enhancing postural control, which can reduce the risk of falls. However, studies to explore more precisely which mechanism of exergaming directly influences older women's ability to balance are still needed.

Objective: Our aim was to evaluate, in a single-group pretest/posttest/follow-up usability study, whether Kinect exergame balance training might have a beneficial impact on the sensory reweighting in women aged over 60.

Methods: A total of 14 healthy women (mean age 69.57 [SD 4.66] years, mean body mass index 26.21 [SD 2.6] kg/m^2) participated in the study. The volunteers trained with the commercially available games of Kinect for Xbox 360 console 3 times (30 minutes/session) a week over a 6-week period (total of 18 visits). Participants' postural sway in both the anteroposterior (AP) and mediolateral (ML) directions was recorded with NeuroCom Balance Master 6.0. To assess and measure postural sensory reweighting, the Modified Clinical Test of Sensory Interaction in Balance was used, where volunteers were exposed to various changes in visual (eyes open or eyes closed) and surface conditions (firm or foam surface).

Results: In the ML direction, the Kinect exergame training caused a significant decrease in the sway path on the firm surface with the eyes open ($P<.001$) and eyes closed ($P=.001$), and on the foam surface with the eyes open ($P=.001$) and eyes closed ($P<.001$) conditions compared with baseline data. The follow-up measurements when compared with the baseline data showed a significant change in the sway path on the firm surface with the eyes open ($P<.001$) and eyes closed ($P<.001$) conditions, as well as on the foam surface with the eyes open ($P=.003$) and eyes closed ($P<.001$) conditions. Besides, on the firm surface, there were no significant differences in sway path values in the AP direction between the baseline and the posttraining measurements (eyes open: $P=.49$; eyes closed: $P=.18$). Likewise, on the foam surface, there were no significant differences in sway path values in the AP direction under both eyes open ($P=.24$) and eyes closed ($P=.84$) conditions.

Conclusions: The improved posturography measurements of the sway path in the ML direction might suggest that the Kinect exergame balance training may have effects on sensory reweighting, and thus on the balance of women aged over 60. Based on these results, Kinect exergaming may provide a safe and potentially useful tool for improving postural stability in the crucial ML direction, and thus it may help reduce the risk of falling.

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KEYWORDS

exergaming; sensory reweighting; older women; mediolateral sway; vestibular

Introduction

Slipping, tumbling, or any other kind of an unintentional loss of balance, which results in a fall and subsequent hospitalization due to injury, is a serious global concern for people over the age of 60 according to the World Health Organization [1].

It has been shown that age-related deficits can manifest in cognitive function [2], in neuromuscular control mechanisms [3,4], and in the following 3 sensory systems: the visual [5], the somatosensory [6], and the vestibular [7]. Various studies have shown that older individuals have a tendency to use proprioception rather than visual and vestibular cues for postural motor control. This dependence on the proprioceptive system also increases with age [3,8]. In direct contrast to this, Haibach et al [9] found that older adults tend to rely more heavily upon their visual input rather than the other sensory systems to compensate for age-related deficiencies.

According to previous studies [10,11], adults tend to experience difficulties in switching quickly between various reliable sensory inputs, which ultimately may contribute to an increased risk of falls. However, Allison et al [12] suggest that this particular process is not impaired among the target population as a direct result of aging. Regardless of whether sensory reweighting deteriorates or remains unchanged with age, therapists should aim to plan programs that can develop these previously mentioned sensory systems and thus decrease the risk of falls.

It has been confirmed that community-dwelling women over the age of 65 are at least two times as likely to suffer hip fractures due to a fall when compared with men [13]. In one study [14], osteoporosis-related fractures in Hungary were investigated and offered incidence data not only on hip, but also on several fractures between 1999 and 2003, when the total population was approximately 10 million inhabitants. According to the data reported in this 5-year period, 404,380 Hungarian women and 206,009 men over the age of 50 had at least one fracture. A possible reason behind this phenomenon might be attributed to the difference between each gender's change in the level of sex hormones during various stages in life. The changes may contribute to older women having a more significant decrease in bone mineral density [15]. Besides age-related hormonal changes, multitasking increases women's gait variability, and this has a direct relationship to the prevalence of falls [16]. Furthermore, elderly women with an abnormal balance while walking are more likely to fall [17]. According to the findings of Qazi et al [18], a static posturography test demonstrated that the mediolateral (ML) component of postural sway is most strongly associated with long-term fracture risk in postmenopausal women. In addition to that, sideward falls are the most frequent cause of hip fractures among older adults [19], meaning that it is of key importance to detect with posturography the quantifiable information on body sway that cannot be visible to the clinicians' naked eyes [20]. Signs of instability are sometimes not immediately apparent in the clinical setting, but sensitive measurements, such as postural sway, can predict the likelihood of falls [18]. For this reason, it is essential to implement training programs that improve sensorimotor control in the critical ML direction.

Recently, exercise games that are played in a virtual, but realistic environment (exergames) have become popular in various fields of research. The use of different types of virtual reality (VR) systems has been considered a beneficial method to improve health gains in different populations and pathological conditions [21]. According to current systematic reviews, video game–based trainings help support physical health [22-25] and cognitive functions among older adults [26-28]. In the last decade nonimmersive VR (without the use of a head-mounted device) exergame trainings with the Kinect system have been proven to be favorable in improving postural control among older adults [29-33]. A recent study revealed significant effects on balance in older adults who had VR exercise training versus an inactive control group [34], as well as a conventional exercise training group [35]. However, the exact mechanism of action of exergaming in improving the balance ability of older adults is a complex process that remains unclear [26]. Thus, in order to provide sound recommendations for their clinical use, the authors suggested conducting further studies to explore more precisely which mechanism of exergaming directly influences an older individual's ability to balance (in other words, what are the causes of the observed changes or what are the improvements from exergame interventions).

It has been suggested that one of the underlying effects of exergames might originate from sensory reweighting. Body sway–based assessments such as the Sensory Organization Test or the Modified Clinical Test of Sensory Interaction in Balance (m-CTSIB) are sensitive tools for measuring sensory feedback reactions and processes during static stance. These measurements can confirm changes in sensory reweighting following exergaming in patients with Parkinson disease [36], in healthy and young adults [37,38], in older adults [39], in healthy women [40], and in women with fibromyalgia [41].

In the past 3 years, the effect of exergaming on sensory reweighting among older women has received little attention despite its clinical importance for physiotherapists. Because of the limited number of studies available on this topic, this usability study is focused on examining the potential effects of a Kinect exergame training on sensory reweighting and balance in the ML direction in healthy older women.

Methods

Participants

For the purpose of this study, healthy, community-dwelling older women above the age of 60 were recruited via local announcements in the senior centers within the city of Szeged, Hungary. Exclusion criteria included self-reported comorbidities (such as cognitive impairment; disorders of the heart; circulatory, musculoskeletal, and respiratory ailments; autoimmune diseases; and neurological conditions), hearing or vision loss, prosthetics or artificial limbs, wounds or corns on lower extremities, and the use of medication that could affect balance or participation in other organized physical training exercise programs. Twenty active, community-based volunteers signed up for the training program; however, due to the exclusion criteria, only 14 of them could participate in the study. This study was performed according to the Declaration of Helsinki and was approved by the Ethics Committee of the University of Szeged, Hungary (registration No. 125/2015 SZTE). All participants gave their signed informed consent before participating in the training program.

Training Protocol

The applied equipment consists of a motion-sensing RGB camera named Kinect (v1), an Xbox 360 console, and video games developed by Microsoft. During the training, pictures of the game's scene and a player's avatar were projected onto the wall via the camera's full-body 3D motion capture.

Before the training program commenced, volunteers had not had any experience with exergames or any of the previously mentioned devices, and so it was important to have an introductory meeting prior to the first training session where instructions were given on how to play the gesture-controlled video games and an opportunity to experience them first-hand. The training took place at Albert Szent-Györgyi Clinical Center's Physiotherapy Department 3 times a week over a 6-week period (total of 18 visits). These sessions were assisted by physiotherapists. Participants were instructed to wear a comfortable outfit and safe footwear for the 30-minute training. Games were chosen based on the type of movements their performance required, with the main aspect being that games had to contain patterns of everyday functional movements which modeled usual, frequent natural motions. Commercially available Kinect games were played by the participants which demanded continual displacement of the participants' center of gravity (COG), transference of weight between lower limbs, and lateral trunk bending and frequent sidesteps. The motor stimulation during gameplay required balanced reactions and continuous postural adjustments associated with fast movement of the legs and arms. During the first half of the training sessions, games that consisted of more foreseeable movements and simple elements (eg, football, skiing) were played. Other more complex games that needed higher cognitive attention and fast reaction (20.000 Leaks, Space Pop, Reflex Ridge, River Rush) were selected to be played in the second half of the training sessions. All participants played the same type of games in pairs, in the same order on every training occasion, but were never allowed to play the same game on 2 consecutive training sessions. During the training, the players' adaptation and progression, as well as the level of difficulty of the game, were continuously recorded and modified based on each participant's overall ranking in the game. Between each game, there was approximately a 1-minute transition time so that players could take a short break.

Measurement

In general, in order to assess an individual's ability to both integrate various senses of balance and compensation, while 1 or more of these senses may be lacking [33], NeuroCom Balance Master 6.0 (Clackamas) and the m-CTSIB [42-44] were used. The posturography measurements were performed at 3 separate intervals: before the first training, after the completion of the training program (posttraining), and 6 weeks after the last training session (follow-up).

The Balance Master 6.0's software provided the location of both the COG and center of pressure across all tests for the m-CTSIB. The m-CTSIB test was initially developed by Shumway-Cook and Horak [45] to differentiate sensory (somatosensory, visual, and vestibular) inputs involved in postural stability during a steady-state balance assessment, and it explored balance on various surface types, with and without vision, using 4 sensory conditions: (1) firm surface, eyes open; (2) firm surface, eyes closed; (3) foam surface, eyes open; and (4) foam surface, eyes closed. The results provided by the Balance Master 6.0's software package gave 3 measurements of COG (3 × 10 s) in the anteroposterior (AP) and ML directions [35]. Based on a previous study [43] with elderly females in all 4 sensory conditions, this test had good to excellent reliability of ML (intraclass correlation coefficient 0.88-0.93) and AP path length (intraclass correlation coefficient 0.85-0.90).

For the assessment of balance on the foam surface, a NeuroCom square foam balance assessment pad (size 46 × 46 × 13 cm) was used. During the assessments, the base of support was fixed, and participants stood comfortably barefooted with arms to their side and their feet next to a mark on the platform. The measurements took place in a quiet room away from distractions.

Data Analysis: Sway Path

The following equations were applied to calculate the sway paths in the ML and AP directions

$$s_x = \sum_{i=1}^{n-1} \sqrt{(x_{i+1} - x_i)^2}$$

$$s_y = \sum_{i=1}^{n-1} \sqrt{(y_{i+1} - y_i)^2}$$

where n is the total number of samples; i is the sample number; s_x is the path length of ML ways; and s_y is the path length of the AP displacements of COG.

The following statistical analysis was conducted using Statistica 13 software (StatSoft). All sets of data were checked for normal distribution using the Kolmogorov–Smirnov test. Factorial analysis of variance was used to analyze sway data of the m-CTSIB test on firm and unstable (foam) surfaces to evaluate the main effects and the influences of the 2 visual conditions (eyes open and eyes closed) at all 3 time conditions (baseline, after the training, follow-up) as within-subjects factors. All values are given as mean (SD). The post hoc test was the

Newman–Keuls test. A level of significance of $P<.05$ was applied.

Results

Overall, 14 female volunteers (mean age 69.57 [SD 4.66] years, mean body mass index 26.21 [SD 2.6] kg/m^2) participated in the study without any dropouts.

Changes in Sway Path During Quiet Stance in the ML Direction

In the ML direction, the Kinect exergame training caused a significant decrease in the sway path on the firm surface with eyes open ($P<.001$) and eyes closed ($P=.001$), and on the foam surface with eyes open ($P=.001$) and eyes closed ($P<.001$) conditions compared with the baseline data. The follow-up measurements when compared with the baseline data also showed significant change in the sway path on the firm surface with eyes open ($P<.001$) and eyes closed ($P<.001$), and on the foam surface with eyes open ($P=.003$) and eyes closed ($P<.001$; Figures 1 and 2). There were no significant differences in sway path values on the firm surface between eyes open and eyes closed conditions during the baseline ($P=.81$), after the training ($P=.30$), and follow-up ($P=.48$) evaluations. However, on the foam surface, results showed a significant interaction of vision × time for the sway path ($F_{2,246}=3.70$, $P=.02$). Before the training, the sway path on the foam (unstable) surface with eyes closed was significantly longer ($P<.001$), whereas after the training the absence of visual information did not result in a significant increase ($P=.16$) of the sway path (Figure 2).

Figure 1. The effect of the Kinect training on sway path (mean [SD]) in the ML direction when standing on the firm surface with open and closed eyes. Statistically significant differences in sway path with eyes open ($P<.001$) and eyes closed ($P=.001$) posttraining conditions compared with the baseline data (asterisk). The follow-up measurements when compared with the baseline data showed statistically significant change in sway path on the firm surface with eyes open ($P<.001$) and eyes closed ($P<.001$) (asterisk). ML: mediolateral.

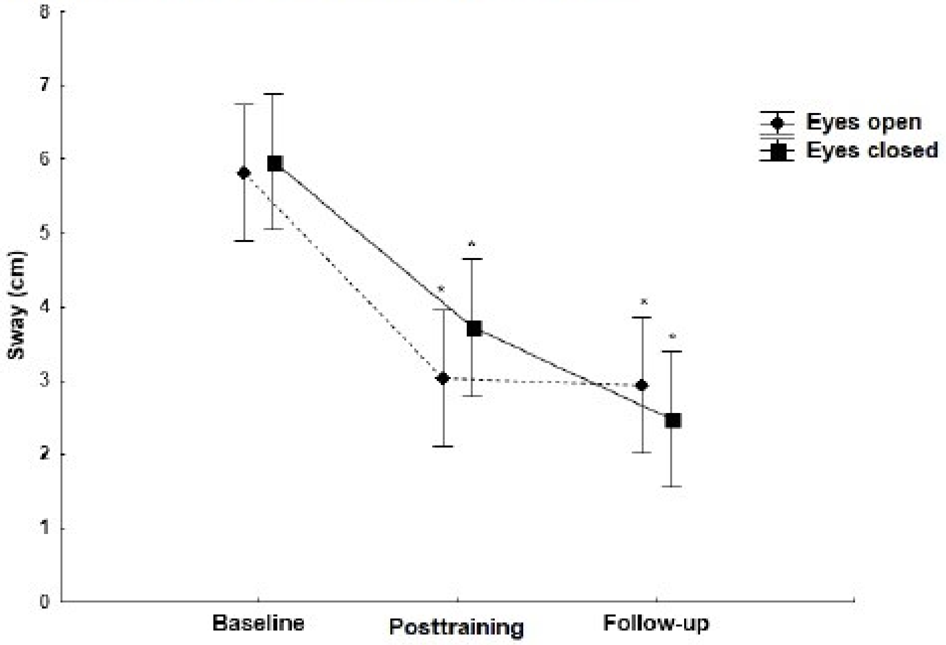
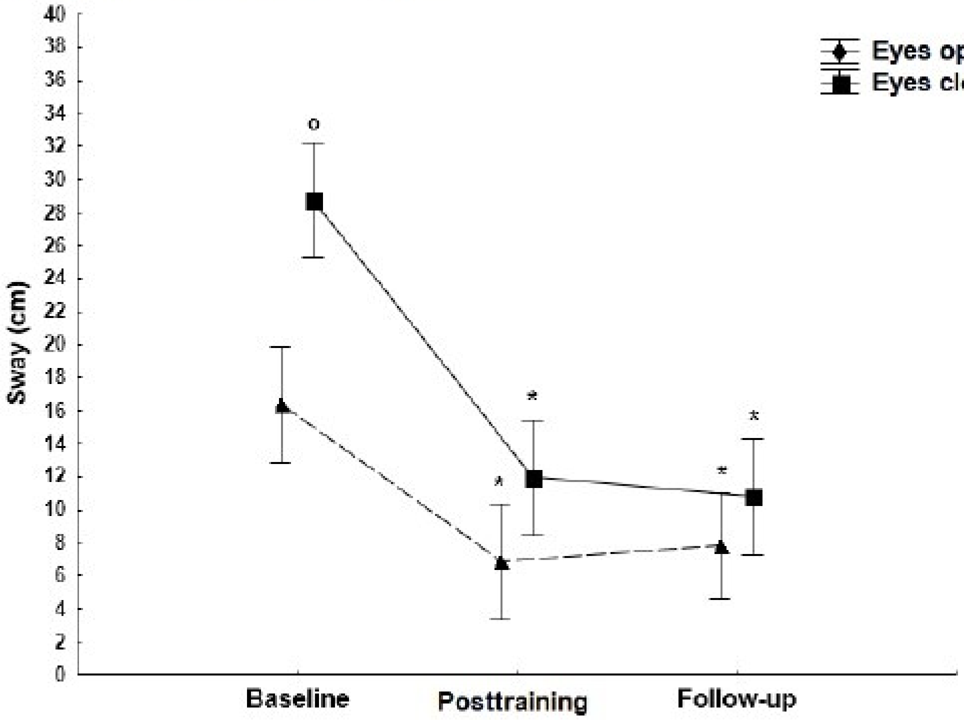


Figure 2. The effect of the Kinect training on sway path (mean [SD]) in the ML direction when standing on the foam surface with open and closed eyes. Statistically significant differences in sway path with eyes open (P=.001) and eyes closed (P<.001) posttraining conditions compared with the baseline data. The follow-up measurements when compared with the baseline data showed statistically significant changes in sway path with eyes open (P=.003) and eyes closed (P<.001) (asterisk). Statistically significant difference in sway path during baseline measurements with eyes closed (P<.001) compared with the eyes open condition (circle). ML: mediolateral.



Changes in Sway Path During Quiet Stance In the AP Direction

On the firm surface, there were no significant differences in sway path values in the AP direction between the baseline and the posttraining measurements (Figure 3; eyes open: P=.49; eyes closed: P=.18). Likewise, on the foam surface, there were no significant differences in sway path values in the AP direction under both eyes open (P=.24) and eyes closed (P=.84) conditions. During follow-up measurements, a main effect of vision was noted; in other words, closing the eyes resulted in a significant increase of the sway path (P<.001; Figure 3). On the unstable foam surface, a main effect of vision was observed and the absence of visual information significantly increased (P<.001) the sway path length in all time conditions (Figure 4).

Figure 3. The effect of the Kinect training on sway path (mean [SD]) in the AP direction when standing on the firm surface with open and closed eyes. No statistically significant differences in sway path values on the firm surface between the baseline and posttraining measurements (eyes open [P=.49] and eyes closed [P=.18]). Statistically significant differences (P<.001) in comparison with the baseline measurement (asterisk) and in comparison with the open eye condition (circle) (P<.001). AP: anteroposterior.

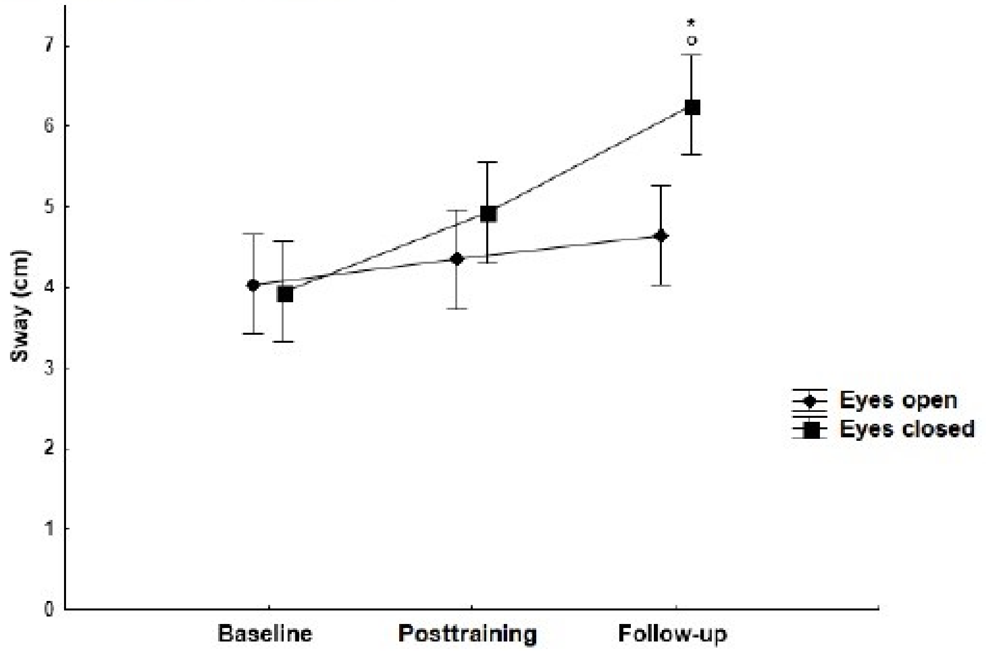
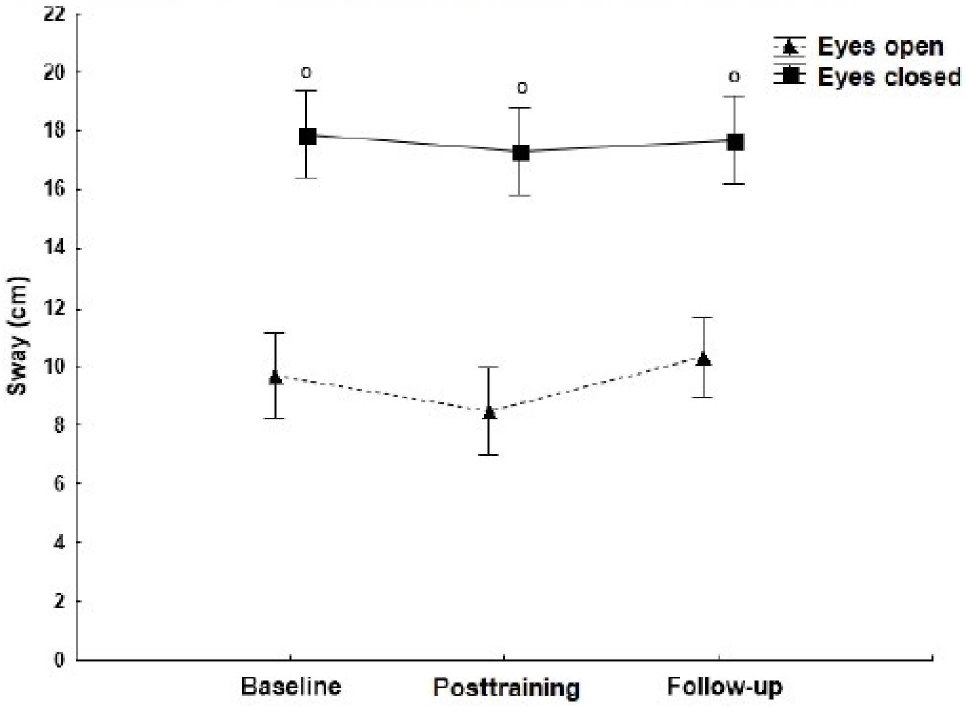


Figure 4. The effect of the Kinect training on sway path (mean [SD]) in the AP direction when standing on the foam surface with open and closed eyes. Statistically significant differences ($P<.001$) in comparison with the open eye condition (circle). AP: anteroposterior.



Discussion

Principal Findings

Several studies have previously confirmed the beneficial effects of exergames on postural control among older adults [22,23,26,29,31-35]. This usability study shows that a simple Kinect game–based balance training might be beneficial for older women by improving balance in the ML direction. This study also demonstrates that exergaming might have a favorable effect in regards to the specific process of adjusting the sensory contributions to balance control [46], namely, sensory reweighting.

Increased Lateral Stability

Based on our study results, an important finding is that the sway path in the ML direction on firm and foam surfaces, with eyes open and closed, improved statistically significantly, whereas no significant change was detected in the AP direction. However, decreased sway path indicates improved stability in the ML direction, which was concluded by Qazi et al [18] as the strongest component of postural sway predicting fractures in postmenopausal women. According to previous studies in the elderly population [47-49], ML sway can often be associated with risk of falls due to decreased proprioception and lower extremity muscle weakness in the lateral direction [50]. In light of the present findings following the training, improved sway results in the ML direction were observed when participants were standing on the foam surface with their eyes open. Significant decrease of ML sway might also implicate an improvement in proprioceptive function following the Kinect training. This finding is similar to the results of Sadeghi et al [51], which suggest that Kinect exergaming can improve proprioception by providing visual feedback and challenging motor skills and visual coordination.

Improvement in Sensory Reweighting

An important finding of this paper is that the Kinect exergame training program significantly reduced postural sway on the foam surface with the eyes closed. Under this condition of the m-CTSIB, the central nervous system mostly relies on vestibular information [45]. In the review by Tahmosybayat et al [52] no exergame study has been presented that would train and assess sensory integration and sensory reweighting. Moreover, the authors suggested that the elements of sensory integration are too unsafe to be trained by disturbed sensory inputs during exergames. However, Roopchand-Martin et al [39] have examined the changes in m-CTSIB results following the Nintendo Wii Fit balance training in community-dwelling adults aged over 60. They found no significant results on the foam surface with the eyes closed condition after the training. By contrast, a Kinect-based physical exercise balance intervention in women with fibromyalgia has revealed significant improvements in the m-CTSIB with eyes closed on foam surfaces [41]. Another study [40] that examined the Wii Fit balance training for healthy women also found similar results: significant sensorimotor improvement in unilateral stance and limb strength. Nitz et al [41] concluded that these findings might not be surprising because the activities included in the Wii Fit training (such as yoga, balance, aerobic, and strength activities) involved considerable single-limb balance requirements and body weight–resistance movements. Although the aforementioned studies [40,41] investigated the effects of exergaming on balance in various sensory conditions with m-CTSIB, sensory reweighting following the trainings has not been proposed in these papers.

In contrast to these results, Yen et al [36] demonstrated that VR balance training significantly improved sensory reweighting in older adults with Parkinson disease when both visual and somatosensory inputs were unreliable. They have suggested that the VR training might be especially beneficial for fall prevention within this high-risk target group, as similar conditions may also occur in reality due to various extrinsic environmental risk factors (inappropriate footwear, poor lighting, slippery surfaces, loose rugs, or uneven steps) [36]. Other studies have found significant improvement in the eyes closed condition on unstable surface following a Wii Fit balance training among young adults [37] and healthy adults [38]. According to these studies [37,38], the reason for the improved vestibular function might be due to the quick displacement of COG in different directions, causing rapid changes in the head position. Similarly, during pretest measurements in this study, closing the eyes on the foam surface resulted in a statistically significant increase in the sway scores in the ML direction; however, posttraining measurements did not show deteriorated sway results. The reason for this might be that after the training, participants shifted to the remaining, accurate source of sensory information, and mainly relied on the vestibular system. Another possible explanation might be that during exergaming, participants had to complete several tasks containing movements such as reaching out and lateral steps while they needed to often change their head position.

Santos et al [53] have suggested that VR therapy enables patients to become immersed in an imaginary world, in which environmental perception is altered by artificial stimuli, thus resulting in a sensory conflict that can act on the vestibulo-ocular reflex (VOR). The central nervous system reacts to vestibular stimulus by reflexes such as the VOR, which stabilizes vision during head motion, and the vestibulospinal reflex, which induces a compensatory body motion to stabilize the head and body, and prevent falls [54]. Thus, types of exergames that require head movements in particular (rotation, lateral flexion, flexion) while players' eyes are focusing (gazing) at one point can function as VOR training. Based on this study's results, the applied Kinect games might improve sensory reweighting in favor of relying on vestibular inputs. In this study, while participants were playing the exergames, they had to keep their eyes on the screen while performing various head and limb movements.

Lessons Learned From Kinect Exergames

Games such as 20, 000 Leaks, River Rush, Reflex Ridge, Super Saver Football mini-game, Space Pop, and Skiing might especially challenge the VOR because they require frequent head displacement movements. Additionally, these games could also improve stability in the lateral direction because of frequent weight shifting and sideward stepping. According to Swanenburg et al [55], exergaming that requires active stepping movements and that involves moving game projection is usable and facilitates gaze stability during head movements, which resulted in improved gait in healthy older adults. As balance is determined by various factors and maintained by complex processes, designing a balance training program requires precisely defining which target components or systems ought to be trained. Health care professionals might use exergames that could display participants' changes of postural sway, reaction time, and limit of stability in various directions. Games which can train VOR by gaze stability during head movements should be provided for continuous monitoring to track players' head movements. As falls occur mostly during activities of everyday life, exergames should be designed to involve functional movements that represent motions from daily life: alternately raising the feet from the ground (eg, stair stepping, stepping out of the bathtub), or reaching movements forward and sideways (eg, taking an item off a shelf below and above shoulder height, cleaning a window, hanging out the washing).

Limitations

This usability study has encountered certain limitations as no sample size calculation was performed, and due to the lack of a control group and the relatively small sample size, the results should be interpreted cautiously. Therefore, these findings are not conclusive. Recruiting volunteers via local paper announcements for exergaming was not sufficient to get the attention we had hoped for. We believe that to attract more participants for future balance training programs, other types of advertisements should be used to generate interest. Posts on social media with video demonstrations and trials could raise interest especially among the youth, who could encourage their older relatives to participate. In this study, only older women participated, but to examine whether there is a gender difference in sensory reweighting following exergaming, future studies should also include a group of male participants. Investigating the effects of exergaming in older individuals with vestibular dysfunctions could also be beneficial, as this population is especially at risk of falling. Although there are studies that have described the positive effects of exergaming on balance ability [56,57] and on higher-order cognitive functions [58] when training independently at home, this study could not have been performed using a home-based exergame program. The reason for that is that the applied commercially available Kinect games are in English and no Hungarian translation is available. Therefore, participants needed assistance with starting and setting up the games, as well as technical help.

Conclusions

In this usability study, women's sway path decreased in the ML direction not only on the firm surface with eyes open, but also on the foam surface with eyes closed as a result of following the Kinect exergame training. These findings might support the idea that although the Kinect exergame training did not specifically contain direct challenging sensory tasks (eg, tilting or unstable surface or closed eyes exercises), the reduced sway results suggest that exergames could additionally result in sensory reweighting. The reason for this might be that the games contained tasks that needed constant gaze stabilizing and frequent head displacements. Therefore, this study's improved sway results in the ML direction might contribute to decreased risk of falls among older women.

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Authors' Contributions

SP and AD share senior authorship.

Conflicts of Interest

None declared.

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Abbreviations

AP: anteroposterior
COG: center of gravity
m-CTSIB: Modified Clinical Test of Sensory Interaction in Balance
ML: mediolateral
VOR: vestibulo-ocular reflex

VR: virtual reality

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