Technology and Health Care 27 (2019) 353–362
DOI 10.3233/THC-191634
IOS Press

Physiological responses and enjoyment of Kinect-based exergames in older adults at risk for falls: A feasibility study

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Received 2 February 2019
Accepted 17 March 2019

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Abstract.
BACKGROUND: Exergaming has the potential to improve physical function, cognition and dual-task function, and could be an effective new strategy for reducing risk of falling in older adults.
OBJECTIVE: To evaluate and test custom Microsoft Kinect-based motion-tracking exergames in older adults at risk for falls.
METHODS: Community-dwelling older adults who reported mobility difficulties or had fallen in the past year played three newly developed exergames (Target Trackers, Double Decision, and Visual Sweeps, 5 minutes each) in random order. Heart rate (HR) was measured during, and blood pressures (BPs), rating of perceived exertion (RPE), and rating of the enjoyment were recorded immediately after each exergame.
RESULTS: Seven participants (median age 75 y; 4 females) completed the study. *There were no adverse events reported during the exergaming session*. Exercise HRs and RPEs were statistically significantly higher than resting for all exergames ($p < 0.05$). The differences were not significant for BPs. Enjoyment ratings ranged from 79.6–90.6% and there were no statistically significant differences between the exergames.
CONCLUSIONS: The newly developed exergames were light in exercise intensity *and enjoyable* for older adults at risk for falls. Future intervention studies are warranted to examine the benefits of exergames for this special population.

Keywords: Exergaming, older adults, dual-task

1. Background

Falls among older adults are a common cause of injury and mortality and are a growing public health problem. In the U.S., approximately 30% of adults over 65 years of age fall each year [1]. In 2015, it was estimated that nonfatal and fatal fall-related medical costs were $50 billion [2]. It is anticipated that the number of falls and the medical cost associated with falls will continue to increase substantially [3].

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Therefore, effective fall prevention programs are necessary to reduce the mortality and fall-related medical cost in the U.S.

Previous studies have identified that in addition to decreases in physical function [4] and cognitive function [5], a decline in dual-task function is one of the major contributors to falls in older adults [6]. Dual-task function is the ability to perform two tasks simultaneously [7]; for example, walking while talking [8]. In addition, the loss of dual-task function may be mediated by the deterioration in both physical function and cognitive function, especially executive function in older adults [6].

Exergaming has drawn attention as a means of promoting health among individuals of all ages [9,10]. Exergaming provides players an opportunity to perform physical exercise in a fun, engaging, accessible and effective manner. In addition to its benefits of promoting physical activity and improving physical function, exergaming has the potential to improve cognitive function and dual-task function, which could be an effective new strategy for reducing fall risk in older adults [11].

Although there are substantial growing interests in using exergaming as a fall preventative intervention, it is unclear what types of exergames yield the most cognitive and dual-task function benefits in older adults. *Previous reviews have indicated that the commercially available exergame console, Nintendo® Wii, was more commonly recommended by physiotherapists to improve balance [12] and was a reliable and valid tool to assess fall risks [13]. Although* several *commercially available* exergames may be appropriate for older adults, *in our opinion*, these exergames only require the players to imitate what they see on the screen, which lacks actively *engaging* the mind. A few studies have created their own exergames for older adults *to actively stimulate the mind* [14–16]. Kayama et al. [15] created a Dual-Task Tai Chi exergame that combined Sudoku, a logic-based number placement puzzle, with Tai Chi movements. Participation in Sudoku or similar puzzles has been shown to be associated with higher cognitive performance and lower risk of developing cognitive impairment and dementia [17]. Similar exergames that train dual-task function may have additional benefits compared to regular exergames. However, previously developed exergames lack variety and progression throughout the intervention periods [14,15].

There are several computer-based brain training programs for improving cognitive function. Researchers have used the commercially available program, Lumosity (*Lumos Lab, San Francisco, CA, USA*), in older adults and found significant improvements in some cognitive abilities [18]. Other researchers used another program, Insight (*Posit Science, San Francisco, CA, USA*), to examine the effect of brain training games on balance and gait. They found that computer-based brain training slowed balance decline and improved dual-task gait, which led to reduced fall risk [19]. Thus, for this study, we developed three exergames that combine computer-based brain training programs that have been shown to improve cognitive function and dual-task gait function, with exercise that has been shown to prevent falls, which could potentially have a significant impact on older adults in reducing their fall risk.

In addition, a pilot exergaming study found that individuals who were in the high cognitive demand exergame group improved their executive function compared to the low cognitive demand exergame group [20]. There was a dose-response of interactive mental challenges with the improvement of executive function [20]. However, exergames' difficulty level was also associated with a decrease in physical movement [21] suggesting the need to have appropriate cognitive and physical stimuli. Moreover, the exergames' levels of difficulty are designed to increase or decrease according to participants' performances. The purpose of this study was to evaluate and test the physiological responses *and enjoyment* of three developed exergames.

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2. Methods

This investigation was the initial phase, testing phase, of the Project Motivating Older Adults via Exercise (MOVE), a quasi-experimental trial designed to examine the effects of exergaming on cognition and dual-task function in older adults at risk of falls. The primary objective of this study was to investigate the physiological responses *and enjoyment* of three newly developed exergames in older adults at risk for falls. All protocols and consent procedures of this study were approved by the Institutional Review Board of the University of Massachusetts Boston.

2.1. Recruitment/Eligibility

All participants were recruited from Boston and surrounding areas utilizing community flyers and email newsletters. Inclusion criteria were as follows: 1) 65 years or older, 2) at risk for falls (reporting at least one fall in the past year or difficulty or task modification with walking 1/2 mile or climbing 1 flight of stairs), and 3) able to communicate in English. Exclusion criteria were as follows: 1) severe vision or hearing impairments, 2) regularly participated in a mind-body exercise for more than one year in the past 10 years, 3) currently engaged in more than 40 minutes/week of moderate to vigorous intensity exercise, 4) diagnosed with degenerative neuromuscular disease, Parkinson's disease, terminal disease or dementing illness. *Inclusion and exclusion criteria for each participant was assessed using a study eligibility questionnaire over the phone.*

2.2. Kinect-based exergames

We used Microsoft's Kinect as the motion-tracking device for the exergames because Kinect is capable of tracking the participant's full-body movements. Such capability allowed us to develop exergames that can track and recognize the participant's pose in real time and provide interactive feedback. Unity (Unity Technologies, San Francisco, CA, USA), a video game development engine, was used to recreate cognitive computerized brain training games and link them to the motion tracking device, Kinect.

The developed exergames combined computer-based brain training games that have been shown to improve cognitive function and dual-task gait function with exercise that prevents falls (Table 1). The cognitive portion of the exergaming was based on three computerized brain training games developed by Posit Science (San Francisco, CA, USA): Target Tracker, Double Decision, and Visual Sweeps. These games had been used in successful cognitive training studies such as ACTIVE [22] and IMPACT [23]. The physical exercise portion of the exergaming was based on modified movements of Tai Chi and balance exercises. Previous studies demonstrated that Tai Chi reduced the risk of falls in older adults [24, 25].

In addition, the objective of the exergames we developed was to train physical function, cognitive function, and dual-task function; therefore, to assign appropriate cognitive stimuli to be challenging but not too overwhelming so that participants will stop moving, our cognitive training portion of the exergames had a slower speed, fewer targets, and a longer time of objects being shown on the screen compared to original computerized training games.

The exergaming session was conducted individually or in groups of two. For each exergame, we introduced the cognitive portion and the physical movement portion of the exergaming separately. We first described the exergame by displaying the cognitive portion of the exergame to the participants using a laptop while disabling Kinect and then intorudced the physical movements associated with the exergame. Once participants understood the concept, the Kinect was enabled and participants were instructed to stand in front of the Kinect and play the developed exergames using the physical movements (Fig. 1).

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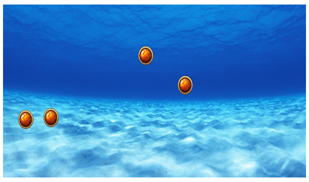
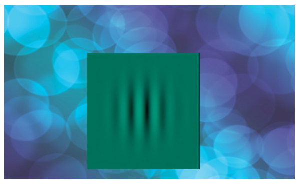
Table 1
Description of three exergames: Target Tracker, Double Decision, Visual Sweeps

Exergaming	Target Tracker	Double Decision	Visual Sweeps
			
Description	The game starts with a few original objects shown on the screen. After several seconds, the objects start to move and identical objects are added. Once the objects all come to a halt, the participant needs to select the original objects. The number of objects and the time that the objects will remain stationary will vary by game level.	The game starts with a car, a route sign and other signs shown on the screen. Once the recognition time is over, the participant needs to select the car that was previously shown and the location where the route sign was shown. The recognition time will decrease as the game progresses. The distance between the car and signs will vary depending on the level. The vehicle will also change to increase the difficulty, for example, a red car or a red truck is shown instead.	The game starts with a green square displayed in the middle of the screen. The lines in the green square then move inward or outward. Once the green box disappears, the participant needs to mimic the directions of the lines. As the game progresses, the speed of the lines will increase, and horizontal lines will be added to challenge the participant further.
Exercise movements	*Tai Chi exercise* Recognition phase – Slow continuous squats with waterfall hands (*Tai Chi*) Picking phase – Easy: Slowly shift weight to the side where the target is located; then open and close hand to select target – Moderate: Slowly lift one leg towards target side; then open and close opposite hand to select target – Hard: Slowly lift one leg and knee extension towards the target side with a heel-toe strike (*slow lunge*); then open and close opposite hand to select target	*Tai Chi exercise* Recognition phase – Easy: Slow shifting of weight (left to right) – Moderate: Slow weight shift with *controlled* hamstring curls – Hard: Slow weight shift and high knees with opposite hand rising Picking phase – While slowly shifting weight (left to right), open and close hands to select	*Tai Chi/balance exercise* Recognition phase – Easy: Side by side stance – knees slightly bent and both feet are side by side – Moderate: Semi tandem stance – knees slightly bent and heel of one foot is beside the big toe of the other foot – Hard: Tandem stance – knees slightly bent and one foot is in front of the other foot – Advanced: One leg stance Picking phase – Depending on the direction of the sweep, begin with both hands in a fist in the center or at the edge, then pull apart or pull towards the center and open fists

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2.3. Measurements

After determining initial eligibility for the study, eligible participants were scheduled for their visit at our research center, GoKids Boston, at the University of Massachusetts Boston. During the visit, we obtained written informed consent and sociodemographic and health characteristics including age, sex, race, educational attainment level, height, and weight were recorded. Resting HR and BPs were taken after participants rested in a chair for 5 minutes. Height was measured using a stadiometer and weight was measured using a digital scale. Participants played three developed exergames for five minutes each assigned in a random order. Physiological responses *and enjoyment* were recorded.

For each developed exergame, physiological responses were evaluated using the Borg's rating of

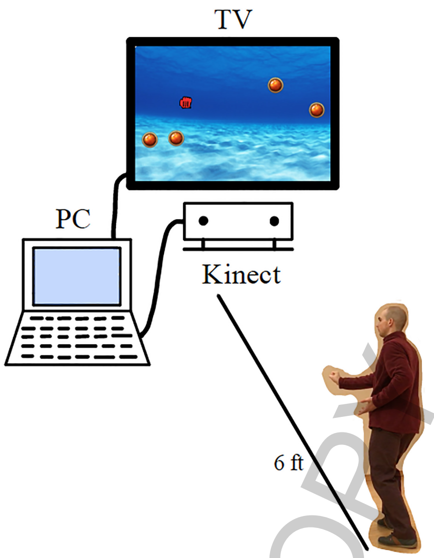

Fig. 1. Exergaming station set up (Target Tracker).

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perceived exertion (RPE) scale [26], a polar heart rate monitor (Polar Electro Oy, Kempele, Finland) and an Omron blood pressure monitor (Omron Health Care, Inc., Lake Forest, IL, USA). Participants' exergames enjoyment levels were evaluated using the 5-item Physical Activity Enjoyment Scale (PACES) [27]. PACES was used in a study examining enjoyment of Wii Fit in adolescents, young adults, and older adults [28] as well as a study examining older adults' enjoyment of exergames [16]. In addition, participants were encouraged to write comments about each exergame.

2.4. Statistical analysis

All analyses were performed using IBM SPSS software version 25 (Armonk, NY: IBM Corp.). Descriptive statistics for demographics and health characteristics were examined. Wilcoxon signed-rank tests were used to compare resting measurements with the median exergames' outcome measurements. Friedman's tests were used to compare resting measures and three exergames on the *physiological* outcome measures. Pairwise comparisons using Bonferroni correction were further conducted to determine which specific pairs were statistically significant. For PACES, a physical activity enjoyment questionnaire, a composite score was calculated by summing up the 5 items. Higher scores indicate greater physical activity enjoyment and a percentage enjoyment score was calculated. Statistical significance was determined by the two-sided p-value < 0.05.

3. Results

Seven community-dwelling older adults were recruited, and all completed the study. The median age of the participants was 75 years (range 66–85 years). There were 3 males and 4 females, and 29% had a college degree (Table 2). The median resting HR was 72 bpm and median resting BP was 125/81 mmHg.

The three newly developed exergames did not cause any injuries or *adverse events*. The median of the average HR, peak HR, BPs, RPE, and enjoyment for the three exergames combined were 84.6 (range:

Table 2
Participant characteristics in older adults

Characteristics	Median (min/max)
Age (years)	75 (66/85)
BMI (kg/m^2)	31.28 (19.62/34.03)
MMSE	24 (20/29)
	n (%)
Gender	
Male	3 (42.86)
Female	4 (57.14)
Education	
$\leqslant$ High school graduate	5 (71.43)
College graduate	2 (28.57)

N = 7. BMI = body mass index. MMSE = mini-mental state examination.

Table 3
Physiological responses to exergames in older adults

	Resting	Exergaming		
	Median (min/max)	Median (min/max)		
		Target Tracker	Double Decision	Visual Sweeps
Heart rate (bpm)	72 (62/90)	82 (77/102)[a,b]	87 (78/98)[a,b]	80.5 (73/99)[a]
Blood pressure				
Systolic (mmHg)	125 (107/149)	132 (114/137)	134 (114/144)	134 (110/153)
Diastolic (mmHg)	81 (64/82)	81 (66/108)	75 (65/91)	78 (66/103)
RPE	6 (6/6)	11 (8/11)[a]	11 (10/13)[a]	11 (6/11)[a]

N = 7. RPE = rate of perceived exertion. Post-hoc test: [a]$p < 0.05$ compared to resting values, [b]$p < 0.05$ compared to Visual Sweeps.

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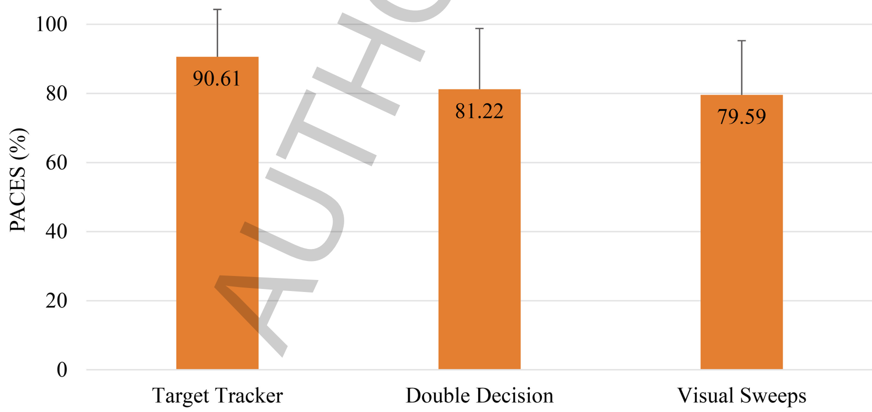

Fig. 2. Enjoyment of exergames in older adults. PACES = physical activity enjoyment scale.

76.7–99.7) bpm ($p < 0.05$, compared to rest), 90.1 (range: 84.7–102.3) bpm, $p < 0.05$, compared to rest), 134.3 (range: 116–140)/78.3 (range: 69.7–88.3) mmHg ($p > 0.05$, compared to rest), 10.3 (range: 9.3–11.7, $p < 0.05$, compared to rest), and 86.7 (range: 61.0–100) % respectively.

The difference in medians were statistically significant for average HR, $\chi^2(3) = 14.3$, $p < 0.01$, and RPE, $\chi^2(3) = 15.7$, $p = 0.001$, but not for systolic BP, $\chi^2(3) = 6.4$, $p > 0.05$, diastolic BP, $\chi^2(3) = 1.8$, $p > 0.05$.

Post-hoc tests were further conducted to investigate the significant differences in HR and RPE. Compared to resting HR, all three exergames indicated statistically significantly higher HRs ($p < 0.05$) and RPEs ($p < 0.05$). There were no statistically significant differences in HR or RPE between the three exergames except for statistically significantly lower HR in Visual Sweeps compared to other exergames. Based on the HR and RPE values following each exergaming session, the exercise intensity of each exergame was relatively light (Table 3). All three exergames were perceived to be enjoyable based on the PACES reported percentile scores (79.6–90.6%, Fig. 2).

From the comments sections, a participant suggested to increase the number of example demonstrations to make it easier to understand the game concept fully. In addition, one participant reported to us that she didn't like the Target Tracker's game because she didn't want to get rid of the original balls. Many participants reported that the exergames required them to concentrate a lot more than they originally thought, but liked them.

4. Discussion

The current study examined physiological responses *and enjoyment* of three newly developed customized exergames specifically designed to train cognition, physical function, and dual-task function on seven community-dwelling older adults at risk for falls. The results suggest that the newly developed exergames were safe, enjoyable, and light in exercise intensity for older adults who are at risk for falls. The three exergames significantly increased participants' HRs and RPEs above the resting state.

The findings of a statistically significant increase in HR and RPE among older adults are in accordance with other exergaming studies [28–30]. Compared to previous studies that examined physiological responses *and enjoyment* on older adults in commercially available exergames, Wii Fit^{TM}, our exergames had similar HR responses as Wii Fit^{TM} activities such as yoga, balance, and strength exergames but lower HR responses than the aerobic exergames [28–30]. In addition, our designed exergames had similar RPE responses to Wii Fit^{TM} activities such as yoga, balance, and aerobic but lower RPE responses than strength activities [29]. The developed exergames had similar physiological responses to commercially available exergames, and they were light in exercise intensity. The exergames' light exercise intensity was in accordance to our expectation. In our 12-week Tai Chi intervention study [31], participants were randomized into a Tai Chi program or a light physical exercise control program. The exergaming movements were based on modified movements of Tai Chi; therefore, we expected the exercise intensity to be similar to that of our previous study. In addition, it is important to note that the increase in RPE could result from both physical and mental exertions. Although we did not observe statistical significance with blood pressures, systolic blood pressure was trended to increase compared to the resting state.

Previous studies with older adults have reported that exergaming has high acceptability based on participant's self-reported enjoyment among older adults [16,28,32,33]. Compared to a previous study that used the same enjoyment scale, PACES, our developed exergames' enjoyment ratings (range: 79.6%–90.6%) were higher to those of commercially available exergames, Wii Fit^{TM} (range: 70.3%–80.4%) [28]. Exergaming enjoyment is particularly important for the next implementation phase since enjoyment has been shown to play a great role in adhering to exergaming intervention [34]. Although our exergaming enjoyment ratings were lower compared to the ratings obtained from a previous 6-week exergaming intervention study during which the researchers examined their own exergames (97%) [16], our exergames have good potential to attain high enjoyment ratings for the intervention after further improvements.

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There are limitations to the study that need to be considered. First, the sample size was relatively small with low statistical power. We recruited seven participants to meet the timeline for the planed intervention phase. Second, the duration in which the exergames were played was relatively short and only had one exergaming session. Although participants received explanation and watched demonstration examples before the five minutes of exergame, participants were likely learning how to play the game for the first 1–2 minutes. It is possible that participants didn't fully understand the game until 2–3 minutes of playing the exergame. The reason for selecting 5 minutes of exergaming exposure for each exergame was to make this study similar to the exergaming intervention protocol. More demonstration and practice time could have improved participant's engagement and understanding of the game logic. Third, participants volunteered to join this study, which could result in a bias for enjoyment responses, *as also limiting the generalizability of our study findings. During our recruitment, we did not include or exclude participants based on their sociodemographic factors (race, ethnicity, education, and income). We were not able to widen our societal representation of our study sample based on our time constraint.* Lastly, our exergames did not have a storyline. *Hence, one participant questioned and did not enjoy the game.* If we had *had* a storyline and if there *were* a reason for choosing the particular object, that may have helped the participants concentrate on the gameplay rather than thinking about why they were picking certain objects.

5. Conclusions

This study was conducted to examine the physiological responses *and enjoyment* of the developed dual-task training exergames for planned exercise intervention for testing the developed exergames' potential benefits. From this study, we learned that further improvements are necessary to use these exergames as an intervention for fall prevention in older adults at risk of falls. Creating a storyline that aligns with the game logic is essential for the participants to fully engage in the exergames. In addition, the introduction, example demonstration, and delivery of the exergames need to be carefully planned. It is imperative for participants to understand the game logic and the movements to train their dual-task function. Lastly, progression throughout the intervention period is crucial to maintaining the high enjoyment which could lead to high retention and attendance. Nevertheless, the results from this study encourage the use of these exergames in future intervention to further examine whether these exergames provide any physical, cognitive, and dual-task function benefits among older adults who are at risk for falls.

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Acknowledgments

We thank Project MOVE study participants for their engagement in this research. Also, we thank the staff members of the Osher Life Long Institute and GoKids Boston, University of Massachusetts Boston who provided valuable support to our project. We thank all research assistants who worked on this project.

Conflict of interest

None to report.

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