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Feasibility randomized controlled trial of a virtual reality exergame to improve physical and cognitive functioning in older people

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Abstract

Background: Falls risk becomes more common with age and is associated with higher rates of disability, mortality, and healthcare costs. Exergames have shown to elicit improvements in prefrontal cortex activity, balance, and postural control of seniors, all of which are associated with fall risk, but it is unknown whether virtual reality (VR) exergames, played using a three-dimensional headset can enhance the effects of cognitive and physiological functioning. **Objective:** Evaluation of the effects of a co-produced VR exergame "Falling diamonds" on physical performance, trunk stability and cognition, three attributes linked to falls risk in seniors. **Methods:** A total of 44 physically active participants aged 60–85 years were randomized to either the immersive VR exergame ($n = 14$), non-immersive exergame ($n = 15$), or control ($n = 15$). Static balance, leg strength, and gait speed were measured by the Short Physical Performance Battery, trunk stability was assessed using the Prone test and cognition was evaluated by the RehaCom screening software at baseline and follow-up at 9 weeks. **Results:** The VR exergame group experienced greater improvements in the cognition measures of selective attention control and speed ($p = .009$, $p = .033$) more than the exergame group ($p = .010$) and control ($p = .049$, $p = .004$). **Conclusions:** The evaluation and delivery methods of VR exergame Falling diamonds are feasible, and trial measures, procedures, and intervention are deemed acceptable by participants. Our findings indicate that using a VR exergame to exercise could improve cognition in seniors.

Keywords: seniors, falls risk, virtual reality exergame, trunk stability, physical performance, cognition

Introduction

Falls risk becomes more common with age and is associated with higher rates of morbidity and mortality, disability, and healthcare costs (Almeida et al., 2019; Granacher, Lacroix, et al., 2013; Masud & Morris, 2001). Prevalence of falls varies between countries, but it is estimated that one-third of the ageing population (over 60 years old) falls once per year and almost half of that falls again in the following year (Jones et al., 2011). Although head and bone injuries are common (World Health Organization, 2018), falling does not always result in harm but can lead to a fear of falling. This can discourage older adults from engaging in their normal daily physical activities and can lead to sedentary lifestyles that can impair physical functioning increasing the risks of falls (Mustafaoğlu et al., 2015). This is further exacerbated by physiological declines associated with ageing including diminishing sensory and motor neurons, bone-related deteriorations, and loss of balance and muscle strength which can all impact levels of confidence in mobility, quality of life and well-being among older adults (Panjabi, 1992).

The results of several studies of randomized controlled trials involving older adults show that regular participation in physical activity improves flexibility, strengthens muscles, and prevents the decline of somatosensory and neuromotor

functions associated with ageing (Carter et al., 2001; Garber et al., 2011). These studies conclude that physical activity is critical for the improvement of balance control which is essential to reducing the risk of falls (Hamacher et al., 2016; Markovic et al., 2015; Omon et al., 2019; Rugelj, 2010). There is also a mounting body of evidence indicating that exercises targeting trunk stability (i.e., maintaining passive spinal column, active spinal muscles and neural control), cognitive function and balance (i.e., centered position of the trunk) simultaneously are more effective in reducing fall risk than do those involving conventional balance or resistance training exercises alone with many of them applied to clinical rehabilitation with varying success (Hamacher et al., 2016; Markovic et al., 2015; Omon et al., 2019). Adherence to and engagement with these types of exercises however can be challenging and discontinuation of such exercise programs are common despite their associated health benefits (Justine et al., 2013). Thus, effective strategies or delivery modes that can improve sustained use of and engagement with these types of exercises are required to motivate self-directed practice outside of supervised one-to-one sessions which may be more costly.

By exergaming, we mean interactive gameplay that involves the performance of some form of physical

movement within an enriched virtual environment that stimulates cognitive functioning (Barry et al., 2014). Common platforms that can host a wide range of exergames include Xbox Kinect and Nintendo Wii. Considerable evidence shows that exergames are a safe and feasible way to deliver physical activity of moderate intensity across a variety of populations including people with special needs, those who are at high risk of cognitive decline and older adults (Hilton et al., 2014; Schättin et al., 2016; Tahmosybayat et al., 2017), and according to anecdotal feedback from older adults, exergames are a fun and engaging way to meet weekly recommendations of physical activity that can be sustained over time (Maillot et al., 2012).

Exercises targeting cognitive functioning, trunk stability, and balance are more effective than conventional resistance training exercises alone because on a functional level, such exercises can emulate the combination of external and internal forces required to challenge trunk stability prompting the management of torques transference and angular moments between the hands and legs while maintaining body equilibrium (Behm et al., 2010). Cognitive activation skills play a substantial role when multiple physical and cognitive tasks are performed together. For example, recall while walking or during a specific locomotor task such as stepping over an obstacle (Haefeli et al., 2011). If functional capacity of either trunk stability or executive function is limited, then this can increase the likelihood of falls in older adults (Granacher, Golhofer, et al., 2013; Granachaer, Lacroix, et al., 2013; Yuan & Raz, 2014).

Exercising using exergames has shown to induce physiological benefits among seniors and has elicited improvements in prefrontal cortex activity, balance and postural control, all of which are indicators associated with declines in the risk of falls (Markovic et al., 2015; Omon et al., 2019; van het Reve & de Bruin, 2014). Virtual reality (VR) games that use a three-dimensional (3D) headset to provide an immersive experience have also shown to be associated with substantial cognitive benefits including improvements in dual-task performance activities and executive functioning (Liao et al., 2019, 2020), but what is unknown is whether the use of immersive VR technology in exergames gameplay can bolster their effects on the cognitive and physiological functioning of older adults. This is likely because compared to gameplay on a flat-screen, a VR 3D headset provides a more engaging experience to the user by eliminating distractions from environmental cues.

The study had three aims. First, to estimate the effectiveness of two types of exergames (immersive virtual reality vs non-immersive) on physical performance, trunk stability and cognition, three key attributes known to be linked to falls risk in active seniors. Second, to assess the usability and feasibility of the "Falling diamonds" exergame intervention, trial procedures and methods for engaging active seniors in exercises targeting cognitive functioning and physical performance. Third, to identify additional intervention content required to increase engagement and uptake of Falling diamonds.

Methods

Participants

This was a parallel randomized controlled feasibility study with nested quantitative and qualitative evaluation. The implementation of the exergame trial ran from November 2019 to March 2020. Participants were recruited between October 2019 and November 2019 using a purposive sampling approach. Seniors were recruited using advertisements which were placed in the local activity center. Interested potential participants were emailed the participant information sheet explaining the purpose of the study along with an informed consent form for them to complete and return if they wished to join the study. Older people aged 60–85 years that were physically active, as assessed by the International Physical Activity Questionnaire Short Form (IPAQ-SF), were potentially eligible. Any participants who had experience of any acute medical conditions within the past three months, severe health problems (e.g., uncontrolled diabetes, major orthopedic or neurological diseases), on a prescription that could affect the nervous system such as psychotropic drugs, any form of cognitive impairment as assessed during the selection process (Mini-Mental State Examination score < 20 points), were excluded from the study.

Using a computer algorithm, participants were randomly assigned (https://www.randomizer.org) into one of three groups. In total, 35 women (10 in VR exergame, 13 in exergame and 12 in control group) and 9 men (4 in VR exergame, 2 in exergame and 3 in control group) were blinded from each other. Their main regular activities before, during and after the intervention (twice a week or more) were Pilates ($n = 9$), Orienteering sport ($n = 2$), Nordic walking ($n = 12$), Dancing classes ($n = 7$), Pool gymnastics ($n = 8$) and Senior gymnastics ($n = 6$). None of the participants had prior experience with immersive virtual reality before the intervention. All participants however knew how to operate a computer, but none had any experience playing video games before the intervention.

Approval (Nr. 96/47722) of the study was granted by the ethics committee of the Latvian Academy of Sports Education. Written informed consent was obtained from all participants in accordance with the Declaration of Helsinki on Ethical Principles in Research Involving Human Subjects.

Intervention procedures
Development of VR exergame Falling diamonds
The game was developed in collaboration with three physiotherapists and tested on and optimised with a group of 10 healthy seniors who were regular clients in physiotherapists' practice.

The Falling diamonds exergame 9-week intervention
Participants within the experimental groups attended the clinic twice a week to play the same exergame. Both experimental groups used HTC VIVE body movement tracker (HTC, New Taipei, Taiwan), a wireless controller comprising of a small sensor fastened under the chest allowing participants interact with the game with trunk movement. The VR exergame group (immersive virtual reality) played

the game using HTC VIVE VR headset while the exergame group (non-immersive virtual reality) played the game on the flat screen of an MSI GS65 Stealth laptop (MSI, New Taipei, Taiwan) without a VR headset. The control group was asked to carry on with their daily activities as usual during the 9-week experimental phase.

In week one, participants were instructed to play the game in a sitting position and in week two, they played the game in a standing upright position alternating afterwards in the following weeks between sitting and standing until completion. Gameplay on both occasions involved the use of a balance board Balanza Ballstep (TOGU, Prien am Chiemsee, Germany). One physiotherapist met with participants at the clinic in a quiet room to help them get set up for gameplay. Before starting the game, participants were asked to perform a 5-min warm-up routine, undertaking a series of instructed exercises to mobilize their joints. They then proceeded with gameplay which lasted for 20 min. This involved memorizing the direction of arrows and responding accordingly afterwards by moving the trunk from the ready position towards one of four directions: left, right, forwards, or backwards depending on the direction of the arrows presented before being prompted to move. Trunk movements were registered using the HTC controller fastened under the chest in near proximity to the body) as shown in Figure 1. Movements had to be at least 2 cm (left and right) and 3 cm (forwards and backwards) to be registered as movement (please see Appendix A for the description of gameplay). At the end of each week, participants completed the IPAQ-SF test. Description of the exergame intervention using Template for Intervention Description and Replication (TIDieR) checklist (Hoffmann et al., 2014) is reported in Appendix B.

Both the experimental groups and control groups were asked to continue with their daily activities as usual during the experiment.

Assessment procedures

Measurements of outcomes were conducted before and after the intervention which lasted for 9 weeks. Baseline information including gender, age, weight and height was obtained and body mass index (BMI, in kg/m²) was calculated.

Cognitive function assessment

The selected tests of cognitive function are associated with the executive function including divided attention, alertness, working memory and selective attention (Alvarez & Emory, 2006; Grady, 2012; Van Vleet et al., 2016). RehaCom software (HASOMED, Magdeburg, Germany) test results are presented as the Z score.

Participants performing the divided attention test were required to take the visual and auditive tasks simultaneously. Five circles with openings at changing positions were observed. When the circle closed, the subject had to press the answer-button. Synchronously, high and low tones were presented alternatively. If the same tone was sounded twice in a row, the participant had to press the answer button (Sturm et al., 1997).

During the selective attention (minimum 2 min) test, a visual object was displayed on the screen. Randomly one of two divergent objects were quickly displayed – either a horizontal striped square or vertical stripes. If a vertical stripe was presented, no action was required, but if a horizontal striped square was presented, participants had to respond by pressing the button (Sturm et al., 1997).

In the alertness (maximum of 6 min) test, the evaluation of tonic alertness, phasic alertness and intrinsic alertness was performed. In the first phase, the response time for reacting to the full quadrate displayed on the screen was measured. In the second phase, a beep sound was played before the quadrate was displayed on the screen and the participant's response time was recorded. The participant was

Figure 1 Game components
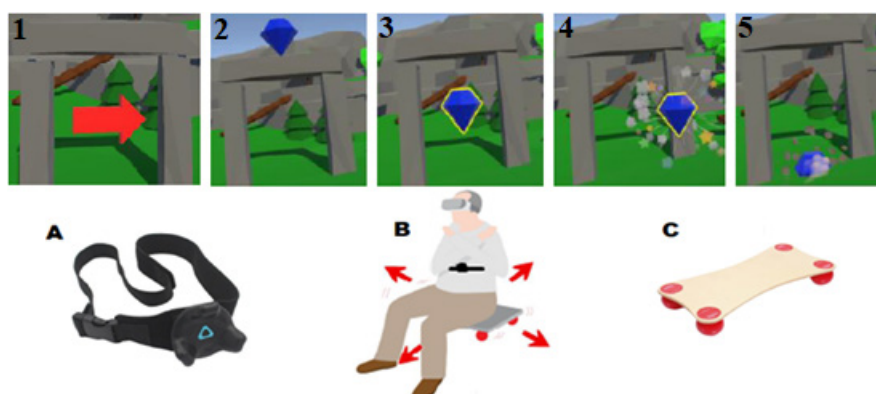
Note. A = sensor; B = senior with the headset and sensor under the sternum sitting on a board; C = Togu Balanza Ballstep mini balance board. Gameplay is shown in squares 1–5 above. The participant at first sees an arrow appearing in the game (square 1) pointing either to the left, right, up, or down. The participant must remember the direction indicated by the arrow before it disappears. Once the arrow disappears, a diamond appears and starts falling from the top of the screen (square 2). Once the diamond starts to glow (square 3), the participant needs to react accordingly by moving its trunk towards the direction indicated by the arrow previously shown. Trunk movements are detected by the sensor attached to participant's trunk. If the participant moves in the correct direction as prompted by the arrow (square 1), the diamond will then be visually shown to move in that direction (square 4). If the participant fails to move in the correct direction, then the diamond will be shown to land on the soil and a point will not be awarded (square 5).

instructed to disregard the beep sound and only respond to the quadrate on screen (Sturm & Willmes, 2001).

During the working memory test (lasting 7 min in duration or by the time the maximum number of mistakes was reached), the participant was presented with 10 dots within a circle on the screen. Each dot individually lighted up in red and changed again to white. The sequence to remember started with two dots. After the pattern was shown, the same sequence had to be marked in the correct order. After two accurate reproductions of the sequence, the number of dots to remember was increased. If the participant failed to recall the sequence, then the number of dots to memorize was reduced (Sturm, 2002).

Trunk stability assessment

A Chattanooga Stabilizer pressure biofeedback cell (Chattanooga Group, Austin, TX, USA) and a stopwatch were used to measure performance on the trunk stability test. Participants were instructed to lay down in the prone position. An inflatable pad was placed centrally beneath the navel of the abdomen. The subject was trained on how to contract muscle transversus abdominis using an abdominal drawing-in maneuver (Richardson et al., 1990). No more than three trials were performed to prevent premature fatigue. Readings were taken at the start and after the 10 s of contraction (time were detected using a stopwatch and three repetitions were performed). Changes in pressure were calculated from the baseline of 70 mmHg (the start of the test) and at the end value (value taken after 10 s) which provided a calculation of the final score of the test (change in the pressure). The mean change in pressure at the end of the three repetitions was calculated. It is established that the normal response of mean change in pressure is ≥ –4 mmHg (Hodges & Richardson, 1996; Richardson & Jull, 1995), –2 mmHg to –4 mmHg is mid-range (uncertain response; Cairns et al., 2000), ≤ –2 mmHg (abnormal response; Richardson & Jull, 1995).

Physical performance assessment

Physical performance was evaluated using the Short Physical Performance Battery (SPPB; Guralnik et al., 1994). The SPPB includes static balance performed with eyes closed and measured in the sequence of three positions: side-by-side, semi-tandem, and full tandem balance. If the participant can successfully hold the first or second positions (side-by-side, semi-tandem) for 10 s, they received 1 point. If the participant can successfully hold the third position (full tandem) for 10 s, they received 2 points. The second variable of SPPB assesses gait speed and involves a timed 4-meter walk performed twice at a self-selected pace with the fastest time counted as relevant. If the time achieved is less than 4.82 s, the participant receives 4 points. The longer the time spent performing the test the lesser the points earned. The same point scoring system applies to the chair stand test which involves standing up 5 times as quickly as possible from a straight-backed chair with arms folded across the chest. Here, if the total time achieved is 11.19 s or less, then the participant receives 4 points. In each of the three tests, a maximum score of 4 points and a minimum

of 1 point can be attained. Participants score no points for any tests they could not perform. (Guralnik et al., 2000; Guralnik et al., 1995).

Statistical analysis

The SPSS Statistics (Version 21; IBM, Armonk, NY, USA) was used for further analysis. Using Kolmogorov-Smirnov test revealed the data to be not normally distributed. Therefore, the Kruskal-Wallis H test was used to assess if there was a significant difference between groups, the Wilcoxon rank test for repeated measures was used to determine any within group difference, and the Mann Whitney U test was used for comparison between groups. Statistical significance was assumed if $p < .05$. In addition to statistical tests, the magnitude of differences between groups was calculated from the results of the experiment. The equation from Rosenthal was used to calculate the magnitude of the effect (Rozenthal, 1991). It was determined whether the differences were small ($r = .10$), moderate ($r = .30$) or large ($r = .50$). All effect sizes calculated can be found in Appendix C.

We also asked participants what they thought of the intervention and what could be included to improve engagement and adherence to the Falling diamonds exergame. These questions aimed to explore overall participant experiences of and satisfaction with the trial process and of the exergame intervention. This was developed by the research team and pilot tested by two authors (AL and ED; please see Appendix D for the brief structured qualitative question guide). Data analysis was conducted by AL using NVivo software (Version 12 for Windows; QSR International, Burlington, MA, USA) to identify relevant quotes.

Results

The flow of participants through the trial is shown in Appendix E. The main characteristics of the participants are presented in Table 1. The main outcomes measured in this study were cognitive function (alertness, selective attention, divided attention and working memory), trunk stability (prone test) and functional performance (static balance, gait speed and leg strength).

The IPAQ-SF scale showed that seniors in all groups had a high level of daily physical activity which was maintained throughout the course of the experiment (IPAQ-SF > 1500 MET min/week; Table 1).

Our results showed that in cognitive scores only the VR exergame group showed statistically significant improvements in selective attention control ($p = .009$) and selective attention speed ($p = .033$) post-intervention (Table 2).

Statistically significant changes in outcomes after the intervention were found between the VR exergame condition and the control group ($p = .004$), and between the VR exergame condition, and exergame group ($p = .049$) for selective attention speed. For selective attention control, statistically significant changes were found between the VR exergame and exergame group ($p = .010$). The results showed statistically significant improvements in the prone test and functional performance of the control group ($p = .005$ and $p = .034$, respectively), the exergame

group (*p* = .001 and *p* = .004, respectively) and the VR exergame group (*p* = .001 and *p* = .014, respectively; Table 2).

Feasibility of use, satisfaction of trial procedures, and suggested improvements of the Falling diamonds exergame

Participants provided qualitative feedback for a series of open-ended questions asked by the physio at the end of each visit (Appendix D). When asked about how they found playing the VR exergame by the physio, participants mentioned that it was enjoyable, adventurous, and "just right" in terms of levels of difficulty:.

> I thought the visual stimuli, for example, the fox and birds gave the effect of surprise and made me feel positive.

They also highlighted that they felt positive and energized after gameplay and that the game is addictive in a positive way because they want to achieve better performance.

> Now, I've noticed that I now feel much more positive and uplifted after playing that game. Ehm, it was just so fun and I really found it enjoyable. I would actually play this in my spare time to relax and destress I think…

Participants were also eager and motivated to complete a given level.

> I found myself immersed within the game because of the virtual reality part of it I think, which is my first time using this kind of technology which I also found really addictive and enjoyable to use.

Many participants reported a sense of achievement and attendance levels in both experimental groups (VR exergame 76% ± 9% and exergame 81% ± 8%).

They indicated that: (1) the Participant Information Sheet provided helped them to decide whether to participate (72%), but some reported that it did not have any impact on their decision to take part (28%); (2) no participants expressed any issues with sharing their personal data including body measurements such as BMI with the physio and researchers; and (3) all participants did not have any issues with playing the exergame in the presence of the physio in the same room and noted that this did not affect their performance.

In relation to suggested improvements, participants were generally satisfied with trial procedures although some mentioned that the visual arrangement of the game could be better presented such as for example, a wider range of animals included (not only foxes and birds) as well as other attractive aspects. It was also noted if they knew the scores of other participants' performance, that could motivate them even more to play the game. They also suggested the value of the provision of structured feedback on their

Table 1 General characteristics of the participants at the baseline

Variable	Control (*n* = 15)	Exergame (*n* = 15)	VR exergame (*n* = 14)
Age (years)	71.67 ± 5.97	73.07 ± 6.31	72.43 ± 5.87
Body height (m)	1.69 ± 0.70	1.64 ± 0.07	1.66 ± 0.09
Body mass (kg)	75.26 ± 11.07	76.47 ± 14.16	72.14 ± 11.04
Body mass index (kg/m^2)	26.39 ± 3.82	28.27 ± 4.30	26.32 ± 3.98
MMSE (score 0–30 pts.)	27.73 ± 1.53	28.33 ± 1.05	28.50 ± 1.99
IPAQ-SF (MET min/week)	1788 ± 167	2067 ± 250	1694 ± 239
DA audio (*Z* value)	0.46 ± 0.29	0.04 ± 0.98	0.46 ± 0.36
SA reaction speed (*Z* value)	0.48 ± 0.63	0.46 ± 0.50	0.45 ± 1.13
SA reaction control (*Z* value)	0.15 ± 0.95	0.80 ± 1.23	0.48 ± 1.50
Working memory (*Z* value)	0.12 ± 0.83	0.92 ± 1.19	0.39 ± 1.39
Alertness audio (*Z* value)	0.79 ± 0.51	0.09 ± 0.82	0.49 ± 0.56
Alertness visual (*Z* value)	1.09 ± 0.65	0.09 ± 0.85	0.60 ± 0.73
Prone test (mmHg)	65.96 ± 2.86	66.44 ± 1.59	66.48 ± 1.18
SPPB (score 0–12 pts.)	10.93 ± 0.96	10.07 ± 1.03	10.64 ± 0.93

Note. MMSE = Mini-Mental State Examination; IPAQ-SF = International Physical Activity Questionnaire Short Form; MET = metabolic equivalent of task; DA = divided attention test; audio = hearing signal (prompting participants to react by pressing the answer-button); SA = selective attention test; visual = visual signal prompting participants to react and press the answer-button; SPPB = Short Physical Performance Battery.

Table 2 Pre- and post-intervention testing scores of the participants (using Wilcoxon rank and Mann Whitney *U* tests)

Variable	Control (*n* = 15)		Exergame (*n* = 15)		VR exergame (*n* = 14)		*p*
	Pre	Post	Pre	Post	Pre	Post	
DA audio (*Z* value)	0.46 ± 0.29	0.38 ± 0.29	0.04 ± 0.98	0.29 ± 0.95	0.46 ± 0.36	0.55 ± 0.27	.06
SA reaction speed (*Z* value)	0.48 ± 0.63	0.33 ± 0.47†	0.46 ± 0.50	0.48 ± 0.49	0.45 ± 1.14	0.87 ± 0.42*†	.02
SA reaction control (*Z* value)	0.15 ± 0.95	0.15 ± 1.00†	0.80 ± 1.23	0.30 ± 0.88#	0.48 ± 1.50	0.44 ± 0.45**†#	.03
Prone test (mmHg)	65.96 ± 2.86	67.07 ± 2.99**	66.44 ± 1.59	69.11 ± 1.78**	66.48 ± 1.18	67.90 ± 1.28**	.11
SPPB	10.93 ± 0.96	11.33 ± 0.82*	10.07 ± 1.03	11.00 ± 0.85**	10.64 ± 0.93	11.29 ± 0.83*	.47

Note. DA = divided attention test; audio = hearing signal (prompting participants to react by pressing the answer-button); SA = selective attention test; SPPB = Short Physical Performance Battery. *,**statistically significant difference within the group between the pre- and post-test (**p* < .05, ***p* < .01). †statistically significant difference (*p* < .05) between the VR exergame and control groups in the post-test. #statistically significant difference (*p* < .05) between the VR exergame and exergame groups in the post-test.

performance of the game at each visit and at each stage either by email or a paper summary.

Participants mentioned that it would be helpful if the researcher sent them a reminder by text message along with a daily phone call before each visit. The reminder should include information on appropriate exercise attire and recommendations for food intake before each visit to the clinic.

> I just think that you could just send me more information on like what to wear and keep me updated on my progress during the whole process and also some advice on what to eat beforehand would be great.

Discussion

This study tested the feasibility of conducting a randomized controlled trial of the Falling diamonds VR exergame which includes a range of simple and low impact exercises designed to improve cognitive functioning, physical performance and trunk stability among seniors. A small sample of active seniors aged between 64 and 85 years concerned about their risk of falls in Latvia was recruited with acceptable uptake, retention, and high participant satisfaction and completion of the VR exergame trial schedule.

Our findings indicate that seniors who exercised using the VR Falling diamonds exergame for 9 weeks significantly improved their selective attention reaction speed more than did those in the no treatment control. Further, seniors in the VR falling diamonds exergame group also experienced significantly greater improvement in selective attention reaction control than did those in the non-virtual exergame and no treatment control. Although all three groups experienced greater improvements in both physical performance and trunk stability after 9 weeks, no significant differences were found between the three conditions for physical performance (Table 2).

In line with these findings, exergames that utilize VR have been shown to improve trunk stability and balance (i.e., physical performance) as well as reduce the risk of falls in seniors (Omon et al., 2019) in comparison with conventional types of exercises (Liao et al., 2019) or exergames (Huang, 2019). However, our data showed only within group and not between group differences for these outcomes as the no treatment control also experienced significant gains similar to those in the exergame groups. This may be partly because our participants assigned to the no treatment control also reported engaging with other forms of physical activity including Pilates, dancing, and Nordic walking amongst others, over the 9-week duration, so it is unclear whether a virtual or non-immersive virtual reality exergame provides any additional benefits over other forms of exercises targeting trunk stability and balance.

In terms of cognitive function, previous evaluations of VR based interventions designed for seniors have shown improvements in dual-task gait performance (i.e., executive function) over a 12-week period (Liao et al., 2019, 2020). Parallel to our findings, seniors exercising using a VR exergame significantly enhanced selective attention (i.e.,

executive function) after 9 weeks than did the no treatment control, but our analyses did not indicate the same effect for the non-immersive virtual reality exergame group, suggesting that the immersive, interactive and engaging environment of VR may be key to improving cognitive function, which has been shown to be an important indicator of optimal gait pattern in several studies (Liao et al., 2019).

The activation of cognitive function can be challenging during specific locomotor tasks like a change in direction or stepping over an obstacle (Haefeli et al., 2011). Especially for those at increased risk of falling (Saftari & Kwon, 2018). Therefore, from the results of the present study, the role of exergame played within VR that targets mentioned components may be worth investigating in the future in those at increased risk of fall as well as the implementation of a VR environment where the visual system is not a priority, also is worth to investigate, because seniors compared to younger people, due to maintaining balance, rely more on the visual organ than on the functioning of the vestibular apparatus and the sensorimotor system (Mahboobin et al., 2005). This can be substantial assuming that an older person frequently trips on objects below eye level (Di Fabio et al., 2005).

The experiment took place on the premises of the Ikskile Municipality Health Promotion Center. The participants were the residents of the Ikskile region. The attendance of both experimental groups was observed high. The most common reason for absenteeism in both experimental groups was a cold or illness. No adverse effects were established in the present research.

This feasibility study of a VR Falling diamonds exergame makes a practical contribution as its application could improve the cognitive function, trunk stability and functional performance of seniors. The use of game content may be more effective in improving the selective attention of seniors than other activities that promote physical and mental activity. Our findings show that a VR exergame under the guidance of a trained specialist is likely to be feasible and can be used as part of physio work with physically active seniors to promote physical and mental activity.

Limitations of the study

The intervention was performed on seniors with high levels of physical activity – the effect of the intervention could be reduced. The results of the study cannot be generalized as the participants were selected from the local region. The positive tendency towards the VR exergame group in cognitive function is preliminary as this is a feasibility study and the number of participants is not sufficient.

Conclusions

The use of a VR exergame intervention as part of physio has shown potential benefits in some of the cognitive scores in seniors with high daily physical activity levels indicating that a 3D VR immersive experience of gameplay could reduce the risk of falls as compared with exergames played on the flat screen which may not be as effective. While most participants were satisfied with the trial

overall, they advised that a wider range of game features including increased opportunities for social comparison (e.g., whereby scores of other participants are shown), structured feedback on individual performance as well as regular reminders would help to improve engagement and retention. In the future, more studies recruiting from a larger population are required, and it is worth evaluating the impact of this type of intervention on seniors with different levels of daily physical activity.

Acknowledgments

Conflict of interest

The authors report no conflict of interest.

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Appendix A
Summary of gameplay

At the start of the game, the player will see an arrow, indicating the direction of movement of its trunk. If multiple arrows appear, then the indicated directions must be remembered in order from left to right. When the arrow disappears, an object (diamond) will appear from the top of the screen and will slowly fall down towards the bottom of the screen. As the diamond reaches the interactive zone, it will flash, informing the player that it must move trunk in the direction previously indicated by the arrow. If the player manages to initiate the correct movement before the object reaches the ground, the palyer will score a point.

The game consisted of 33 levels and in each level, speed of objects and number of arrows gradually increased. From level 10 onwards, the movement indicated by the arrow was audible. This means that an audible signal sounds when the object falls. The sounding position is variable. After the beep, the user is given one second to complete the movement. From level 12, the game includes a distraction where an animated bird may fly over the player, or a fox can appear and walk away. The level reached by the participant was saved so that in the next visit participant could continue the game from level before the one that was reached in the last visit. During the game, participant could reach the next level if it completed 70% of the given tasks. On average, each level of the game took 2–3 min to complete.

Appendix B
Description of exergame intervention using TIDieR checklist

Item number	Item
What	
1	Virtual reality exergame to improve physical and cognitive functioning in older people
Why	
2	In a number of trials, exercising using exergames has shown to induce physiological benefits among seniors and has elicited improvements in prefrontal cortex activity, balance and postural control, all of which are indicators associated with declines in risk of falls. Virtual reality (VR) games, which involves the use of a three dimensional (3D) headset and can provide an immersive experience, is also associated with substantial cognitive benefits including improvements in dual task performance activities and executive functioning, but it is unknown whether the use of virtual reality technology in exergames gameplay can bolster their effects on cognitive and physiological functioning of older adults. The main goal of the study was to estimate the effectiveness of two types of exergames (virtual reality vs non-virtual reality) on physical performance, trunk stability and cognition, three key attributes known to be linked to falls risk in active seniors.
Materials	
3	The HTC VIVE system with VR headset and tracker (controller placed under participant's sternum and used to move the objects in the game) was used during the 30-min intervention (https://www.vive.com/eu/product/vive/). TOGU Balanza Ballstep (https://www.togu.de/balanza-ballstep) also was used during the game. Participant was either sitting or standing on it. While standing a support chair was placed in front of the participant to avoid fall risk. A physiotherapist assisted whole intervention.
Procedures	
4	Participants within the experimental groups attended the clinic twice a week to play the exergame. In week one, participants were instructed to play the game in a sitting position and in week two, they played the game in a standing upright position. Gameplay on both occasions involved the use of a balance board. One physiotherapist met with participants and helped them get set up for gameplay. Before starting the game, participants were asked to perform a 5-min warm-up routine, undertaking a series of instructed exercises to mobilize their joints. They then proceeded with gameplay which lasted for 20 min and involved small movements of the trunk from the ready position towards either one of four directions: left, right, forwards, or backwards. Trunk movements had to be at least 2 cm (left and right) and 3 cm (forwards and backwards) to be registered as movement by the controller (please see Appendix A for description of gameplay).
Who provided	
5	The intervention is intended to be used by health care professionals (i.e., certified physiotherapists).
How	
6	The intervention can be delivered face-to-face.
Where	
7	The intervention was delivered in Health Promotion Center.
When and how much	
8	Participants within the experimental groups attended the clinic twice a week (for 9 weeks) to play the exergame. Before starting the game, participants were asked to perform a 5-min warm-up routine, undertaking a series of instructed exercises to mobilize their joints. They then proceeded with gameplay which lasted for 20 min. The game consisted of 33 levels and in each level, speed of objects and number of arrows gradually increased. From level 10 onwards, the movement indicated by the arrow was audible. This means that an audible signal sounds when the object falls. The sounding position is variable. After the beep, the user is given one second to complete the movement. From level 12, the game includes a distraction where an animated bird may fly over the player, or a fox can appear and walk away. During the game, the participant could reach the next level if it had completed correctly 70% of the given tasks. Each level of the game to complete took on average 2–3 min of game time. At the end the participant performed stretching exercises lasting about 5 min for main muscle groups.
Tailoring	
9	The level reached by the participant was saved so that in the next visit participant could continue the game from level before the one that was reached in the last visit.
Modifications	
10	There were no modifications of the game during the experiment.
How well-planned, actual	
11	The attendance of each session was documented by the physiotherapist who assisted the intervention at a particular day. Documentation at the end of the experimented was delivered to researchers.

Appendix C
Effect sizes between the groups

Variable	VR exergame vs Control	VR exergame vs Exergame	Exergame vs Control
Divided attention audio	.37	.26	.21
Selective attention reaction speed	.52	.36	.12
Selective attention reaction control	.36	.47	.14
Prone test	.06	.32	.34
Short Physical Performance Battery	.03	.17	.21

Appendix D
Interview Schedule: Patient questions

Introduction and questions prior to starting the exergame session
How do you feel today?
Prompt: How do you feel right now physically? Mentally?

Questions after the session
How do you feel after that?
Are you experiencing any dizziness, feel nauseous or have a headache?
Did you experience any dizziness, feel nauseous or have a headache during the game?
What did you think of the Exergame? Did you like it?
Did you enjoy the game? Was it interesting or boring?
What could be added/included to motivate you to keep playing this type of game?
How difficult was it to reach the next level of the game in today's session?
How do you evaluate your performance today?
Did you experience any difficulties standing or sitting down?
Did you experience any issues with your trunk movements?
Prompt: Did you find this easy or exhausting for you during or after game play?

Appendix E
CONSORT 2010 Flow Diagram

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┌─────────────────────┐      ┌──────────────────────────────────┐
│                     │      │  Assessed for eligibility (n = 65) │
│    Enrollment       │      └──────────────────────────────────┘
│                     │                      │
└─────────────────────┘                      │        ┌─────────────────────────────────────────┐
                                             │──────▶ │ Excluded (n = 21)                        │
                                             │        │  ♦ Not meeting inclusion criteria (n = 0)│
                                             │        │  ♦ Declined to participate (n = 21)      │
                                             ▼        └─────────────────────────────────────────┘
                                  ┌─────────────────────┐
                                  │ Randomized (n = 44) │
                                  └─────────────────────┘
```

Allocation

Allocated to VR exergame intervention (n = 14) ♦ Received allocated intervention (n = 14)	Allocated to exergame intervention (n = 15) ♦ Received allocated intervention (n = 15)	Allocated to control intervention (n = 15) ♦ Received allocated intervention (n = 15)

Follow-Up

Discontinued intervention (n = 0)	Discontinued intervention (n = 0)	Discontinued intervention (n = 0)

Analysis

Analysed (n = 14) ♦ Excluded from analysis (n = 0)	Analysed (n = 15) ♦ Excluded from analysis (n = 0)	Analysed (n = 15) ♦ Excluded from analysis (n = 0)