An innovative videogaming device for motor control training in older adults with the aim of reducing the risk of falls: a feasibility study

By,

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ABSTRACT

Background: Falls are the primary cause of injury and death in older adults. Falling is linked with postural instability and muscle strength decline, which can result in mild or severe injuries, that lead to daily activities restriction or even hospitalization. As the global life expectancy rises, it is crucial to identify and rehabilitate individuals at risk of falling, thus reducing the number and risk of falls in the elderly. Postural control training and muscle strengthening are the primary aspects of rehabilitation that current studies target, and in recent years exercise in the form of video-gaming has emerged as

an alternative to a traditional approach.

Aim: In this study, we investigated the use of the innovative gaming device "MOVOBall" for motor control training in older adults. We constructed an exercise regime and performed a pilot study to evaluate whether it could reduce the risk of falls in the elderly population.

Methods: Four participants aged 71 to 78 years (74.5 ± 3.04; mean ± SD) were recruited in a motor control training program with the MOVOBall device and performed the Timed Up and Go (TUG) Test, which was the outcome measure of the study. The TUG Test took place in the first and the last day of data acquisition, before and after the training program. The training program consisted of 8 sessions, 30 minutes each, 2-3 times per week.

Results: The results were analyzed with a paired t-test ($p=0.3$) and although not significant, the time values of the TUG test were reduced in most subjects.

Conclusions: Despite the small sample size that prevented the study from having statistically significant results, the outcomes of the study are promising and show that the MOVOBall device might be an effective way to reduce the risk of falls in the elderly population.

Key words: falls risk, older adults, rehabilitation, motor control training, videogame

1. INTRODUCTION

The modern world consists of aging societies (Park, 2017). In the US, older adults (people over 65 years of age) comprise the fastest-expanding section of the population, as it is estimated that their number of 31 million in 1990 will more than double to 68.1 million by 2040 (Stevens and Olson, 2000). In Europe, according to Eurostat, adults aged over 60 will increase by 2 million per year in the forthcoming years (Vazquez et al., 2018) and it is estimated that by 2050 older adults will account for 2 billion people worldwide (Toledo and Barela, 2010). A leading, global cause of morbidity and mortality for older adults are falls (Lukaszyk et al., 2016). Based on the World Health Organization (WHO) review, 28-35% of people aged over 65 fall every year and 32-42% of people aged over 70 are fallers, indicating a link between age increase and falls risk increase (Park, 2017). Regarding the cost of falls, it is substantial (Pohl et al., 2014) and it has been estimated that in the US alone the number is around 20 billion every year (Greene et al., 2010).Therefore, it is crucial to secure quality of life in older adults by developing and optimizing programs that protect their health and also prevent overburdening the health care systems (Vazquez et al., 2018).

Falling is heavily associated with a deterioration in postural stability and muscle strength and is usually manifested as walking and turning problems (Greene et al., 2010). Injuries, daily activities restriction, disability and death are some of the most critical outcomes resulting from falls in the elderly population (Vellas et al., 1998; Lukaszyk et al., 2016). Specifically, 20-30% of falls result in mild to severe injuries and more than 50% of them require hospitalization (Park, 2017). A two-year longitudinal study of falls in 482 community-dwelling older adults reported that 5-10% of falls resulted in significant injuries such as fractures and head trauma that required hospital care (Vellas et al., 1998). Considering the increasing global life expectancy, it is evident that falls are a crucial health concern for older adults worldwide, therefore it is vital to identify individuals at risk of falling in order to prevent and reduce falls in older adults (Lukaszyk et al., 2016, Vellas et al., 1998, Pohl et al., 2014).

Current literature suggests strength and balance training as two of the principal components of a fall prevention strategy (Clark and Kraemer, 2009). A systematic review of fall prevention studies conducted by the Cochrane Collaboration concluded that physical therapy interventions that incorporate balance and progressive muscle strength training significantly reduce the risk of falls (Gillespie et al., 2009; Clark and Kraemer, 2009). In recent years, with the emergence of exergames (videogames that require physical activity), balance and strength training exercises are performed in an interactive and effective way (Vazquez et al., 2018). Betker et al. (2006) and Tamura et al. (2006) in their studies found that videogame-based rehabilitation programs in the elderly improved their dynamic balance control, and Betker et al. established that videogame exercises prompted the subjects to increase the amount of training as well as their attention span during training. Additionally, exergames improve cognitive function in older adults, and studies have shown that its decline is linked to impaired gait in the elderly (Vazquez et al., 2018; de Bruin and Schmidt, 2010). Finally, the systematic review and meta-analysis of the efficacy of videogame-based interventions conducted by Vazquez et al. concluded that they objectively improved muscle strength, balance, postural control and gait (Vazquez et al., 2018).

Although the effectiveness of a traditional strength and balance training regime has been routinely established, few studies so far have investigated exergaming in older adults as an intervention to enhance postural stability and reduce risk of falls (Clark and Kraemer, 2009). Therefore, in this present study we investigated the feasibility of the use of an innovative gaming device called MOVOBall for motor control training in older adults, in order to determine whether this novel rehabilitation approach improved postural and gait control with the aim of reducing the risk of falls.

2. METHODS

2.1. Participants

Five healthy participants (4 male, 1 female, mean ± standard deviation; age: 75.8 ± 3.76 years, weight: 73.1 ± 11.9 kg) were recruited for this study from the wider community in Birmingham, UK. Inclusion criteria were: (1) community-dwelling adults, (2) 65-90 years of age. Exclusion criteria were: (1) severe cardiovascular, neurological or psychiatric disease, (2) severe visual and auditory impairments, (3) being on a high dose of opioids (>30 mg of morphine equivalent dose) and (4) being under physiotherapy treatment in the last 3 months.

2.2. Study design

This was an interventional study conducted at the School of Sport, Exercise and Rehabilitation Sciences in the University of Birmingham. Specifically, the data acquisition and training sessions took place in the Human Movement Laboratory at the Centre of Precision Rehabilitation for Spinal Pain. The study was advertised via the University website, People in Research website and the Birmingham 1000 Elders group, which is a community-based organization that provides direct involvement in research studies and is a crucial resource for the Healthy Ageing Research Journal. The School of Sport, Exercise and Rehabilitation Sciences Ethics Committee approved the study (MCR050319-1). All participants provided written consent prior to participation and were free to withdraw from the study at any time.

2.3. Study setting

The study consisted of two data acquisition sessions, one in the beginning and one at the end of the training program, and 8 training sessions (3-4 consecutive weeks, 2-3 times per week, for 30 minutes each), a total of 10 laboratory sessions. Two study investigators were responsible for the data acquisition as well as the participants' training sessions.

2.3.1. First data acquisition session and TUG Test

During the first data acquisition session, the participants first provided their written consent to take part in the study. A wireless single sensor (IMU, G-Walk Sensor from BTS Bioengineering, Italy) was used to accurately obtain the time taken to perform the TUG test (Negrini et al., 2016). The participants were then instructed to perform the Timed Up and Go (TUG) Test, which was the outcome measure of the study. The TUG Test was performed three times in order to ensure greater accuracy in measurement and the average was taken for further analysis.

The TUG Test is a mobility test commonly used worldwide to assess functional mobility issues in the community-dwelling elderly population (Shumway-Cook, Brauer and Woollacott, 2000; Greene, Redmond and Caulfield, 2017). It is recommended as a routine screening test for falls risk by the British Geriatric Society, the American Geriatric Society as well as the National Institute for Health and Care Excellence (NICE), and is included in their guidelines for balance and gait assessment in elderly for the prevention of falls (Barry et al., 2014). The test is composed of separate tasks that try to reproduce in a clinical environment elements of daily living activities, such as gait and balance maneuvers, and the time required for its completion is greatly correlated to the functional mobility level (Negrini et al., 2016; Shumway-Cook, Brauer and Woollacott, 2000).

In order to perform the TUG Test the participants were instructed to rise from a chair (seat height ≈ 46 cm), walk at a comfortable speed on a 3 meter line on the floor, turn 180 degrees at the designated spot, walk back to the chair and sit down (Barry et al., 2014; Greene, Redmond and Caulfield, 2017).

Figure 1. G-Walk Sensor – BORGinsole Website, 2020.

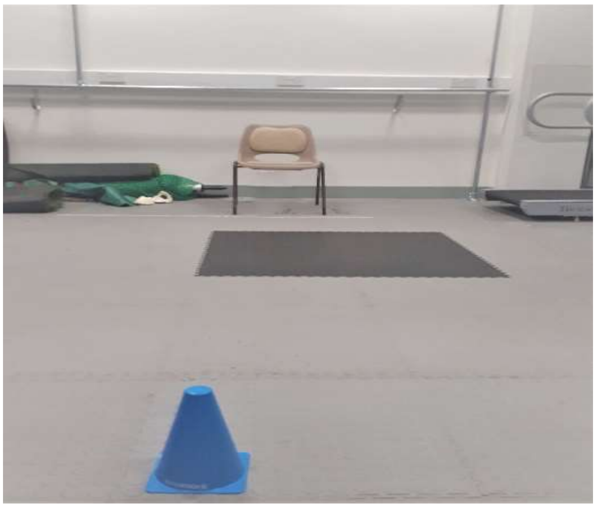

Figure 2. The TUG Test

2.3.2. MOVOBall training session

The MOVOBall is an innovative gaming device that was developed by Movonix, a company that creates interactive fitness products that challenge the traditional approach to exercise (Fitness Gaming Website, 2020).The revolutionary technology connects the MOVOBall motion cradle with the user’s smartphone and a TV device, and converts the Swiss ball that sits on the cradle into an interactive fitness device (Fitness Gaming website, 2020). In this study the MOVOBall was used for balance training, as well as trunk and lower limb strength training.

During the training session, the participants sat on the Swiss ball placed on the MOVOBall cradle, that was connected to a TV screen and underwent a motor control training that lasted 30 minutes. They were instructed to roll on the ball a few degrees in order to play the following two games:

Bouncy Ball: They had to move the Swiss ball side to side in order to control the moving ball on the screen and collect the stars that were on their path.

Monkey Island: They had to move the Swiss ball side to side as well as forwards and backwards in order to control the moving monkey on the uneven platform on the screen and collect the bananas that were on their path.

Both games had levels of progressive difficulty. Every time the participants completed one level of the game successfully, they moved on to the next level. Each participant was granted a few-minute break between the two games in order to avoid any form of exhaustion. During the training session, two investigators were always close to every participant in order to monitor their training, as well as prevent the unlikely occurrence of a fall.

Figure 3. MOVOBall - Fitness Gaming Website, 2020.

Figure 4. The MOVOBall system

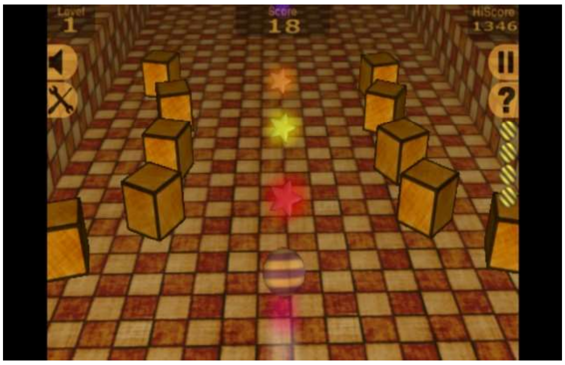

Figure 5. Bouncy Ball

Figure 6. Bouncy Ball

Figure 6. Monkey Island

Figure 7. Monkey Island

2.3.3. Last data acquisition session

During the last data acquisition, the participants performed the TUG Test with the use of the G-Walk Sensor. The TUG Test was performed three times and the average was taken for further analysis. They were also asked to fill in the System Usability Scale (SUS), the Technology Acceptance Model (TAM) and the Physical Activity Enjoyment Scale (PACES) (Nawaz et al., 2016; Wuest et al., 2014; Lewis and Sauro, 2018; Mullen et al., 2011). Responses for the SUS were recorded with a 5-point Likert scale ranging from “strongly disagree” (rated as 1) to “strongly agree” (rated as 5), responses for the TAM were recorded with a 7-point Likert scale ranging from “strongly disagree” (rated as 1) to “strongly agree” (rated as 7) and responses for the PACES were recorded with a 7-point Likert scale ranging from “quite disagree” (rated as 1) to “quite agree” (rated as 7).

2.4. Statistical analysis

The data were collected and analyzed with the use of the IBM SPSS Statistics 25 software program. Descriptive statistics were used for age, height and weight variables of the participants, and these were demonstrated as mean ± standard deviation. The paired-sample t test was performed to analyze the data from the first and last session of the TUG Test. The level of significance was set to $p < 0.05$. The data were independently analyzed by two study investigators.

3. Results

One participant didn't follow through with the last data acquisition session, therefore the subject's results were excluded from analysis. Consequently, the data from the remaining four participants (male, mean ± standard deviation; age: 74.5 ± 3.04 years, height: 1.73 ± 0.03 m, weight: 76.3 ± 11.2 kg) were used for analysis.

3.1. Timed Up and GO (TUG) Test results

The mean value of the TUG Test pre-training was 10.53 seconds (ranging from 9.68 to 11.44 seconds) and post-training 9.75 seconds (ranging from 8.12 to 11.71 seconds). The TUG Test time was reduced in 3 participants and increased in 1 participant. The paired t-test was run for the results pre- and post-training and the results didn't yield a statistically significant difference ($p=0.3$).

3.2. System Usability Scale (SUS) and Technology Acceptance Model (TAM) results

The SUS mean score was 53.1, ranging from 40 to 62.5. The results show that the MOVOBall has poor rating regarding usability perception, based on the guidelines that classify scores of 51-68 as "poor", 68 as cut-off value for "okay", and scores over 68 as "good".

Results for the TAM are shown in Table 1.

Table 1. Technology Acceptance Model Questionnaire Items

Item	Score
Perceived Ease of Use	5.1 ± 0.3 (4.75-5.75)
Perceived Usefulness	5.0 ± 0.7 (4.25-6.25)
Attitude Toward Using	3.8 ± 0.2 (3.5-4)
Behavioral Intention to Use	5.8 ± 4.8 (2.6-6)

Data is shown as mean ± standard deviation (range) values.

3.3. Physical Activity Enjoyment Scale (PACES) results

Results revealed that three participants "quite enjoyed" MOVOBall, one participant "slightly enjoyed" MOVOBall, three participants rated MOVOBall as "quite fun", one participant rated MOVOBall as "slightly fun", three participants were "quite happy" to use MOVOBall and one participant was "slightly happy" to use MOVOBall.

4. Discussion

In this study we observed that the MOVOBall training program had positive effects in the postural and gait control of older adults, as TUG Test time was reduced in most participants, therefore reducing the risk of falls. Moreover, MOVOBall was considered easy and fun to operate.

4.1. TUG Test

TUG Test results were not statistically significant due to the small sample size however, time test values were reduced in three out of four subjects, showing the effectiveness of the MOVOBall program on balance and gait in the elderly. Healthy older adults also tend to have a high baseline score, allowing little room for improvement post-test (Fang et al., 2019). In this study all four participants were healthy. Current literature reports different threshold time values to discriminate older adults with a high falling risk that range from 10-33 seconds, however a score of 13.5 seconds is commonly used to identify community-dwelling elders with an increased falls risk (Nordin et al., 2008; Barry et al., 2014). In this study, we used a score of 13 seconds as cut-off value to discriminate elders with a high risk of falling. All participants had baseline scores below the threshold value before the training program, with a mean score of 10.53 seconds. After the training program the mean score was reduced to 9.75 seconds, therefore TUG Test mean time was improved by 0.83 seconds.

Older adults prone to falling have longer TUG Test times than non-fallers and longer TUG Test times are correlated with a higher risk of falling (Green et al., 2010; Green, Redmond and Caulfield, 2017). Recent literature suggests that the TUG Test alone is moderately precise in falls risk assessment (Greene, Redmond and Caulfield, 2017), and a study found that the TUG test has low specificity and sensitivity in identifying elders at risk of falling (Barry et al., 2014). However, another study in community-dwelling elders found that the TUG Test had 87% sensitivity and 87% specificity in classifying fallers and non-fallers (Shumway-Cook, Brauer and Woollacott 2000).

Lately, many studies use various inertial sensor-based methods to obtain quantitative data from mobility tests like the TUG Test, in order to improve accuracy in evaluating falls risk in the elderly population (Greene, Redmond and Caulfield, 2017). Green, Redmond and Caulfield (2017) in their study showed that TUG Test time alone was 60.1% accurate in identifying potential fallers, a sensor-based assessment was 72.7% accurate, and their combination had an accuracy of 76.3%. In this study, the use of the G-Walk sensor in combination with the TUG Test is supported by the study of Negrini et al. (2016), who showed that the G-Walk sensor was a valid and reliable tool for measuring TUG Test time and improved TUG Test specificity.

4.2. TAM, SUS and PACES Questionnaires

Medium to high scores for the four TAM items were found. Participants generally found the MOVOBall easy to understand and to operate. *Perceived Ease of Use* scores showed that MOVOBall was considered easy to use without much mental effort required and *Perceived Usefulness* scores showed that MOVOBall was deemed a useful device for motor control training. However, *Behavioral Intention to Use* scores, although significantly high, showed a diverse attitude toward using the MOVOBall, ranging from a quite negative attitude to a very high one. Moreover, *Attitude Toward Using* was the only item with a medium score, suggesting that participants had some difficulty accepting the MOVOBall, which was not related to understanding or operating it. This difficulty can be explained by the inherent risk of falling when training with the MOVOBall, and it was voiced by one participant that said assistance was needed to remain on the ball throughout the training program. These findings are consistent with the SUS scores, that showed poor usability perception. However, based on the PACES scores, participants found MOVOBall fun in general and were happy to exercise with it.

4.3. Exergames

MOVOBall was considered useful and entertaining and participants were positive about using it on a regular basis. This finding is in line with the systematic review and meta-analysis by Fang et al. (2019), who found that older adults expressed willingness to continue using the exergame after the similar intervention program. This inclination to exergaming directly targets a crucial matter in clinical practice, which is low adherence to training (Fang et al., 2019). Adherence is challenging because traditional exercises are frequently considered tedious and unexciting, people lose interest and consequently discontinue the training program, without achieving long-term benefits (Fang et al., 2019). However, studies that compared exergames to traditional exercises found that participants considered exergames more interesting and satisfying, thus possibly becoming more motivated to continue exercising (Fang et al., 2019). Therefore, MOVOBall seems an effective method to encourage a greater volume of self-regulated training outside therapy sessions in comparison to traditional training, thus achieving better training results.

4.4. Limitations

This study had a few limitations. The sample size was small and could not yield statistically significant power. The participants were healthy older adults with good TUG Test baseline scores, therefore there was little room for improvement. Since all baseline scores were below the threshold value, there was inadequate sample representation. One participant had increased TUG Test scores post training, although they remained lower than the threshold value. A possible explanation for this is the fact that his gait consisted of short strides, before and after training, a gait feature that is linked with increased risk of falling (van Schooten et al., 2015). The other three participants walked in long strides and had improved test time post-training. Therefore, it is possible that the MOVOBall training was effective for participants with good gait quality before the training but was not effective enough for participants with lesser gait quality.

The training ineffectiveness can also be explained by its duration. In the systematic review and meta-analysis by Fang et al., which was based only on randomized control trials (RCT) for greater evidence quality, they investigated the effectiveness of exergaming on balance in healthy older adults and found that it had a positive effect (Fang et al., 2019). The studies had however, on average, a training protocol of two to three sessions per week, 40 minutes each, for approximately 8 weeks (Fang et al., 2019). The training and session duration differ significantly from our study and this might be another reason why the training effects were not statistically significant. Nevertheless, the studies had significant variations in training duration (3-15 weeks) and in session duration (15-60 minutes), which makes it difficult to determine the ideal training volume (Fang et al., 2019). In another systematic review and meta-analysis by Lesinski et al., that examined the dose-response correlation of traditional balance training in healthy older adults, researchers noticed the largest improvement in balance when the training program was three sessions per week, 30-45 minutes each, for 11-12 weeks (Lesinski et al., 2015). This also differed significantly from our training protocol.

4.5. Future research

Future studies that investigate the effects of exergaming on balance in older adults should include a larger sample size for statistically significant results. A diversity in the baseline scores of the outcome measures of the participants for better sample representation is recommended. The optimal volume of an exergaming training program and subsequent training effects remain unclear and further investigation is needed however, a balance training protocol of three training sessions per week, 40 minutes each, for 8-12 weeks, seems to be the most effective.

Our study was conducted in a supervised clinical environment and showed the effectiveness of the MOVOBall as a motor control training program for older adults. However, these findings need to be transferred into a home-exercise framework, where older adults exercise unsupervised, therefore the issues of effectiveness and safety in a home environment arise. However, Karahan et al. conducted an RCT of 100 older adults and compared the effectiveness of an exergaming program (EG) to a traditional home-exercise program (HE) regarding balance (Karahan et al., 2015). They found that only the EG group had significantly improved TUG Test time, and they also had improved scores in balance and functional walking assessments (Karahan et al., 2015). There were no complications during and after the EG training, which was interpreted as a sign of safety (Karahan et al., 2015). Based on these findings, we conclude that MOVOBall will be a safe and effective home-exercise method for motor control training in older adults, however more high-quality studies are needed to confirm this.

Finally, currently there is no gold standard for the quantification of postural control and therefore falls risk assessment (van Diest et al., 2013). Apart from the TUG Test, which is a valid and reliable clinical test, future studies should also utilize biomechanical assessments, like the use of the force plate, in order to obtain objective data of balance control in various conditions (Fang et al., 2019). Recent technology also provides us with the unique possibility of measuring balance while playing exergames, data that are easily acquired and quantified within minutes, and can be stored and compared with results over time, thus allowing individualized training programs to be formed (van Diest et al., 2013).

5. Conclusion

MOVOBall is an effective method for motor control training for older adults that improves balance and gait quality, and subsequently reduces the risk of falls. More high-quality studies are needed to further investigate the effectiveness of exergames as motor control training in older adults.

REFERENCES

Park, S. (2017). Tools for assessing fall risk in the elderly: a systematic review and meta-analysis. Aging Clinical and Experimental Research, 30(1), pp.1-16.

Stevens, J. and Olson, S. (2000). Reducing falls and resulting hip fractures among older women. Home Care Provider, 5(4), pp.134-141.

Vázquez, F., Otero, P., García-Casal, J., Blanco, V., Torres, Á. and Arrojo, M. (2018). Efficacy of video game-based interventions for active aging. A systematic literature review and meta-analysis. PLOS ONE, 13(12), p.e0208192.

Toledo, D. and Barela, J. (2010). Sensory and motor differences between young and older adults: somatosensory contribution to postural control. Brazilian Journal of Physical Therapy, 14(3), pp.267-275.

Lukaszyk, C., Harvey, L., Sherrington, C., Keay, L., Tiedemann, A., Coombes, J., Clemson, L. and Ivers, R. (2016). Risk factors, incidence, consequences and prevention strategies for falls and fall-injury within older indigenous populations: a systematic review. Australian and New Zealand Journal of Public Health, 40(6), pp.564-568.

Vellas, B., Wayne, S., Garry, P. and Baumgartner, R. (1998). A Two-Year Longitudinal Study of Falls in 482 Community-Dwelling Elderly Adults. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 53A(4), pp.M264-M274.

Pohl, P., Nordin, E., Lundquist, A., Bergström, U. and Lundin-Olsson, L. (2014). Community-dwelling older people with an injurious fall are likely to sustain new injurious falls within 5 years - a prospective long-term follow-up study. BMC Geriatrics, 14(1).

Greene, B., Donovan, A., Romero-Ortuno, R., Cogan, L., Ni Scanaill, C. and Kenny, R. (2010). Quantitative Falls Risk Assessment Using the Timed Up and Go Test. IEEE Transactions on Biomedical Engineering, 57(12), pp.2918-2926.

Gillespie, L., Gillespie, W., Robertson, M., Lamb, S., Cumming, R. and Rowe, B. (2009). Interventions for preventing falls in elderly people. Cochrane Database of Systematic Reviews.

Clark, R. and Kraemer, T. (2009). Clinical Use of Nintendo Wii™ Bowling Simulation to Decrease Fall Risk in an Elderly Resident of a Nursing Home. Journal of Geriatric Physical Therapy, 32(4), pp.174-180.

Betker, A., Szturm, T., Moussavi, Z. and Nett, C. (2006). Video Game–Based Exercises for Balance Rehabilitation: A Single-Subject Design. Archives of Physical Medicine and Rehabilitation, 87(8), pp.1141-1149.

Tamura, T., Sekine, M., Schinchi, T., Yuji, T., Higashi, Y. and Fujimoto, T. (2007). IEEE Engineering in Medicine and Biology Society.

Shumway-Cook, A., Brauer, S. and Woollacott, M. (2000). Predicting the Probability for Falls in Community-Dwelling Older Adults Using the Timed Up & Go Test. Physical Therapy, 80(9), pp.896-903.

Greene, B., Redmond, S. and Caulfield, B. (2017). Fall Risk Assessment Through Automatic Combination of Clinical Fall Risk Factors and Body-Worn Sensor Data. IEEE Journal of Biomedical and Health Informatics, 21(3), pp.725-731.

Barry, E., Galvin, R., Keogh, C., Horgan, F. and Fahey, T. (2014). Is the Timed Up and Go test a useful predictor of risk of falls in community dwelling older adults: a systematic review and meta- analysis. BMC Geriatrics, 14(1).

Negrini, S., Serpelloni, M., Amici, C., Gobbo, M., Silvestro, C., Buraschi, R., Borboni, A., Crovato, D. and Lopomo, N. (2016). Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering. pp. 310-317.

de Bruin, E. and Schmidt, A. (2010). Walking behaviour of healthy elderly: attention should be paid. Behavioral and Brain Functions, 6(1), p.59.

Fitness Gaming. (2020). MOVOBall Motion Cradle Uses Smartphone Motion Games to Get Users Fit. [online] Available at: https://fitness-gaming.com/news/home-fitness/movoball-motion-cradle-uses-smartphone-motion-games-to-get-users-fit.html [Accessed 25 Jan. 2020].

Nawaz, A., Skjæret, N., Helbostad, J., Vereijken, B., Boulton, E. and Svanaes, D. (2016). Usability and acceptability of balance exergames in older adults: A scoping review. Health Informatics Journal, 22(4), pp.911-931.

Wüest, S., Borghese, N., Pirovano, M., Mainetti, R., van de Langenberg, R. and de Bruin, E. (2014). Usability and Effects of an Exergame-Based Balance Training Program. Games for Health Journal, 3(2), pp.106-114.

Lewis, J. R. and J. Sauro (2018). "Item Benchmarks for the System Usability Scale." Journal of Usability Studies 13(3): 158-167.

Nordin, E., Lindelöf, N., Rosendahl, E., Jensen, J. and Lundin-olsson, L. (2008). Prognostic validity of the Timed Up-and-Go test, a modified Get-Up-and-Go test, staff's global judgement and fall history in evaluating fall risk in residential care facilities. Age and Ageing, 37(4), pp.442-448.

Mullen, S., Olson, E., Phillips, S., Szabo, A., Wójcicki, T., Mailey, E., Gothe, N., Fanning, J., Kramer, A. and McAuley, E. (2011). Measuring enjoyment of physical activity in older adults: invariance of the physical activity enjoyment scale (paces) across groups and time. International Journal of Behavioral Nutrition and Physical Activity, 8(1), p.103.

Fang, Q., Ghanouni, P., Anderson, S., Touchett, H., Shirley, R., Fang, F. and Fang, C. (2019). Effects of Exergaming on Balance of Healthy Older Adults: A Systematic Review and Meta-analysis of Randomized Controlled Trials. Games for Health Journal.

Lesinski, M., Hortobágyi, T., Muehlbauer, T., Gollhofer, A. and Granacher, U. (2015). Effects of Balance Training on Balance Performance in Healthy Older Adults: A Systematic Review and Meta-analysis. Sports Medicine, 45(12), pp.1721-1738.

Karahan, A., Kucuksarac, S., Basaran, A. and Yildirim, P. (2015). Effects of Exergames on Balance, Functional Mobility, and Quality of Life of Geriatrics Versus Home Exercise Programme: Randomized Controlled Study. Central European Journal of Public Health, 23(Supplement), pp.S14-S18.

van Diest, M., Lamoth, C., Stegenga, J., Verkerke, G. and Postema, K. (2013). Exergaming for balance training of elderly: state of the art and future developments. Journal of NeuroEngineering and Rehabilitation, 10(1), p.101.

van Schooten, K., Pijnappels, M., Rispens, S., Elders, P., Lips, P. and van Dieën, J. (2015). Ambulatory Fall-Risk Assessment: Amount and Quality of Daily-Life Gait Predict Falls in

Older Adults. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 70(5), pp.608-615.

FIGURE REFERENCES

Fitness Gaming. (2020). MOVOBall Motion Cradle Uses Smartphone Motion Games to Get Users Fit. [online] Available at: https://fitness-gaming.com/news/home-fitness/movoball-motion-cradle-uses-smartphone-motion-games-to-get-users-fit.html [Accessed 7 Feb. 2020].

BORGinsole. (2020). BTS G-Walk sensor. [online] Available at: https://podiatrist.borginsole.com/en/bts-g-walk-sensor [Accessed 7 Feb. 2020].