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A Step in the Right Direction: Evaluating the Effectiveness of Customized Stepping Game Software and Balance Boards for Balance Rehabilitation Therapy and Measurement

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***Abstract*— The incidence of falls significantly increases with age in older populations. Traditionally, exercise interventions have been effective in improving balance and strength, thereby reducing the number and risk of falls. To minimize costs, to make exercise more engaging, and to reduce the burden on therapists, the use of serious gaming using virtual reality technologies has become more common. These gaming systems allow the evaluation of compensatory strategies to reduce falls. One of the easiest compensatory strategies to reduce falls is to step forward. To evaluate stepping, the time it takes to step, response times, and reaction times, a stepping game was developed using two Nintendo Wii Balance Boards™.**

The objective of this study was to investigate the stepping game system for its efficacy as a supplemental balance therapy by evaluating functional outcomes and participant satisfaction. The game was able to identify changes in performance measures (response time, reaction time and step time) for some participants over the span of the exercise program; however, a larger sample size and a stricter protocol is necessary to evaluate the clinical significance.

***Clinical Relevance*— The stepping game appears to be more sensitive to detecting change in balance related measures including step time, reaction time, response time, than the Berg Balance Scale.**

I. Introduction

Falling is a serious issue among the elderly population. The incidence rate of falls increases rapidly with age such that approximately 30% of individuals over the age of 65 report falling at least once per year [1-5]. For this age group, falls are the most common cause of injury [1, 6], accounting for nearly 70% of emergency room visits [5]. Similar to the frequency, the impact and associated complications of falls increases steadily with age, also making falls the leading cause of death due to injury for this population [5,6,7].

The Berg Balance Scale (BBS), is a standardized assessment tool developed and widely used in clinical situations to measure functional balance in the elderly [8]. It consists of 14 tasks that increase in difficulty, from standing to sitting to standing on one foot. For each task, the participants are given a score on a scale from 0 to 4 depending on their ability to complete the task. The criteria for the score is explicitly outlined on the scale. The scores for each task are then added together to yield a total score out of 56. A higher score indicates better balance and a score of less than 50 has been shown to be predictive of multiple falls [9].

Gamification and virtual reality are being used more frequently for rehabilitation purposes to transform the repetitive nature of rehabilitation exercises into interactive entertaining games [10]. Serious games, digital games used for purposes other than mere entertainment [11], are an innovative means of delivering therapy to improve the user's performance in a specific area. These systems can greatly benefit users by providing the user with instant feedback and a more engaging experience [12,13]. Furthermore, the ability for these systems to be used at home with remote supervision or check-ups could increase adherence to rehabilitation and exercise [10,14].

A customized stepping game was designed for balance rehabilitation purposes using two Nintendo™ Wii Balance Boards™ (WBBs) [15]. A user is prompted to take steps from one WBB onto targets on the other WBB and the game increases in difficulty by means of requiring increased accuracy in target stepping as the game progresses. The Centre of Pressure (COP) data is collected from each WBB over the span of the game and is analyzed for response time, reaction time and step time performance. The stepping game was piloted by people with various conditions that affect their balance [15]. In that study, 104 participants were grouped according to the reason for referral. Deacon et al. concluded that the system was able to identify differences between the response time of healthy participants and participants with conditions that affect balance, such that response times for people with balance issues were between 1.17 and 2.26 times the response times of healthy people; however, it was unable to distinguish among conditions. A relationship between a decrease in median response time and an increase in BBS was found with strong evidence that people with a history of falls correlated to a higher mean response time than those who did not have a history of falls.

The objective of this testing was to evaluate the functional outcomes and participant satisfaction over a ten-week period using the stepping game to supplement traditional therapy as compared to traditional therapy alone. We also sought to further assess the usability and efficacy of the system as a rehabilitation tool.

II. Methods

A. Participants and programs

Individuals over the age of 60 years who attend a weekly or bi-weekly exercise program were asked to participate in this study (n=12). The participants were recruited from two different older adult exercise programs in Kingston, Ontario.

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Nineteen participants from the programs agreed to participate in the study. Seven participants did not complete the study as a result of loss of interest or illness (Table 1).

Ethics clearance was granted by the Queen's University Health Sciences & Affiliated Teaching Hospitals Research Ethics Boards (HSREB). Once verbal and written informed consent was obtained from each individual, a short health form was completed to collect personal health information regarding conditions or injuries that may affect one's balance or vision. Participants were excluded from the study if they were unable to mobilize independently with or without an aid, to undertake a functional activity assessment or to shift weight bilaterally pain free (or within tolerable pain levels). Individuals with epilepsy or severe visual impairments were also excluded to avoid issues with the video/screen-based technology.

B. Procedure

A Berg Balance Scale assessment was completed one week prior to the study and the participants from exercise programs A and B were stratified randomly into control and test groups based on these initial BBS scores. The goal was to reduce bias by randomising the participants while ensuring a matched or similar distribution of BBS scores. At the end of the test protocol however, from program A, there were four test and three control participants and from program B, there were three test and two control (due to dropouts). The control group underwent baseline assessments using the stepping game in week one and once more at the end of the program in week ten for comparison of stepping performance. Between the assessments, they participated in their regularly scheduled exercise classes. The test group was assigned balance exercises using the WBBs and stepping game technology, once a week, throughout the ten weeks, which supplemented their regularly scheduled exercise class. BBS assessments were repeated on the last week for each participant to evaluate whether clinical observable changes in balance could be detected. The game took between 10-15 minutes to complete each week for each participant.

C. Gaming Protocol

We implemented the aforementioned customized stepping game designed for balance rehabilitation using two Nintendo™ Wii Balance Boards (Fig. 1) [15]. A user is prompted to take steps from one WBB onto targets on the other WBB and the game increases in difficulty by encouraging increased accuracy in target stepping as the game progresses. We analyzed the Centre of Pressure (COP) data from each WBB over the span of the game and analyzed the data to calculate response time, reaction time, and step time performance.

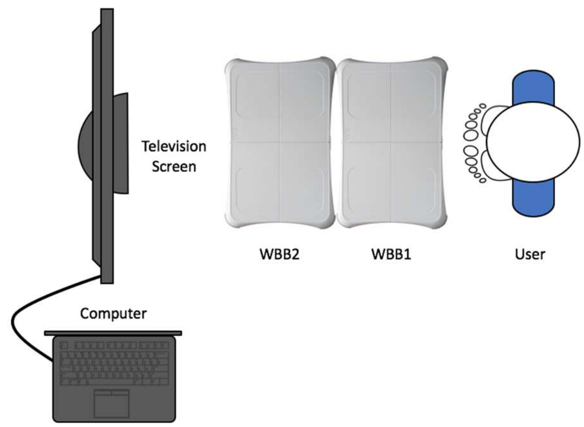

Figure 1. Stepping game system components and set-up.

III. Results

A mixed linear model with SAS software was used to make statistical inferences about the means of the data while still accounting for covariance and repeated measures. Data was transformed to satisfy the assumption of normality necessary for a mixed linear model. The Tukey-Kramer method was used post-hoc to compare the mean response time between programs, weeks and test groups.

A. Berg Balance Scores (BBS)

The participants were originally stratified into control and test groups based on their BBS scores (BBS = 52-53), however, after dropouts there was a larger variation of mean BBS scores between groups (BBS = 50.3-54.5). Furthermore, the allocation was randomized to eliminate bias in variables other than BBS score. At the end of the study, for program A, the mean BBS score for the test group decreased by 0.5 points and increased by 1.3 points for the control group. For program B, there was a noticeable increase of 2.67 in mean BBS score for the test group, while the mean BBS score for the control group remained unchanged.

B. Response Times

The mean response times in week 1 and week 10 for both the control and test participants for program A and program B are plotted in Fig. 2 (these are the non-transformed data for graphical representation to enable a better understanding of meaningful differences). Statistical differences were found using the inverted values to satisfy the normality assumption. The mean response times decreased from week 1 to week 10 for three of the four program and group combinations. The test group from program A, the test group from program B

TABLE I. Demographic Description of Participants from Each Program

Program	Times/ Week	Class Length	Original Number of Participants			Final Number of Participants			
			Total	Test	Control	Dropouts	Total	Test	Control
A	1	90 min	8	4	4	1*	7	4	3
B	2	60 min	11	6	5	6**	5	3	2

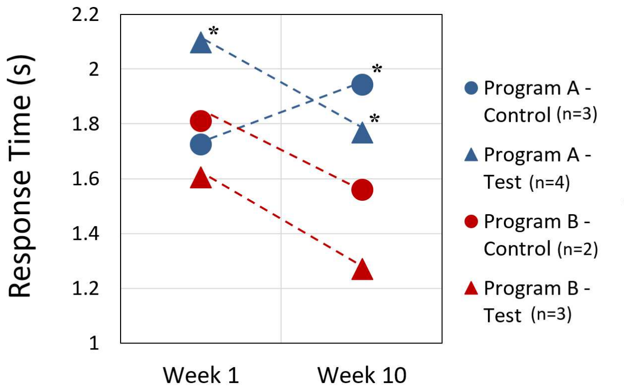

Figure 2. Response times in week 1 and week 10. Dashed line denotes significance. * denotes significance difference in means with program B test in week 10.

and the control group from program B, all had improved response times. The control group from program A, however, did not improve and actually increased in response time from week 1 to 10.

C. Reaction Times

The mean reaction times for the group and program combinations are similar to the response times. Once again, the reaction times decreased from week 1 to week 10 for the test group from program A and the test and control groups from program B and increased for the control group from program A (Fig. 3). Significant differences between means were found using the transformed data (inverted to satisfy normality assumption).

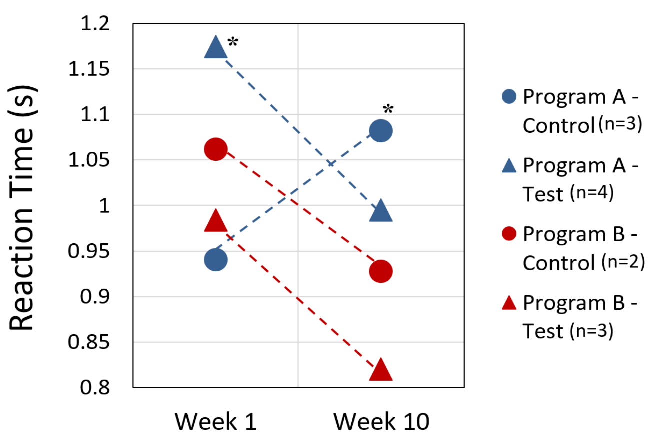

Figure 3. Reaction times in week 1 and week 10. Dashed line denotes significance. * denotes significance difference in means with program B test in week 10.

D. Stepping Times

Step time data was logarithmically transformed to satisfy normality. Unlike the reaction time and response time, there does not appear to be a difference in mean step time between the control and test groups from a statistical perspective, thus the group data is collapsed in Fig. 4. From week 1 to week 10, there appears to be a significant decrease in mean step time for program B and no significant change for program A.

E. Qualitative Observations

In addition to obtaining quantitative data with the balance boards, qualitative observations of the participants were also recorded. It was evident that some participants appeared to have poor spatial awareness resulting in the inability to consistently step towards the target location. From a cognitive processing perspective, the participants had to observe an event on a television screen mounted in front of them and translate that information into the task of stepping in the right direction towards the target. This was difficult for several participants. A few participants did not understand the interface at the beginning of the study and were confused about with which foot to step. Performance appeared to improve towards the end of the test session in week 1 and was noticeably more consistent in week 2 in the test group.

It is also important to note that attendance was not consistent among all participants. One participant in the control group for program A missed two weeks of the exercise class to go on vacation and another had surgery on her eye, which resulted in her absence for two weeks and a very limited level of physical exertion during the remaining 3 classes. A test participant in program B was absent for one week to accompany another participant to the hospital for an unrelated injury. The hospitalized participant was reported as a dropout. Another test participant in program B was in attendance but did not complete the game in one of the test weeks as a result of technical difficulties. Lastly, one control participant in program B was absent from 2 classes and another was absent for 5, however their exercise class was twice a week so in total they attended 18 and 15 classes respectively.

IV. Discussion

A. Berg Balance Scale Scores

Although there were some small BBS changes observed between weeks 1 and 10, it is difficult to conclude that an improvement in physical function resulted. A study that investigated the test-retest reliability found that despite the BBS having a high intraclass correlation coefficient, a change of 8 points is required to reveal a genuine change in clinical

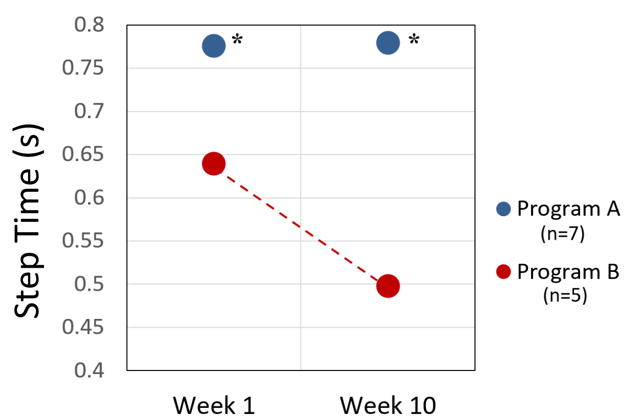

Figure 4. Step times in week 1 and week 10. Dashed line denotes significance. * denotes significance difference in means with program B week 10.

function between two assessments rather than a change due to measurement error [16]. The largest change observed in this study was 6 points for one individual and less than 3 for the mean of a group, thus suggesting that the improvements may not be significant. Other studies have found that absolute reliability of the BBS varies across the scale, in that it is stronger at the ends and weaker towards the middle [8], [17]. In a study by Donoghue et al. it was found that the minimal detectable change (MDC) is 4 points in a patient with an initial score within 45-56, 5 points in a patient with an initial score within 35-44, 7 points in a patient with an initial score within 25-34 and 5 points in a patient with an initial score within 0-24 [17]. By these MDCs, the participant's improvement from 43 to 49 can be considered a significant change, however, the group BBS means still do not appear to be significant. Downs [8] identifies a limitation of the BBS that may explain these results. In his paper, he acknowledges the presence of a ceiling effect for the BBS when used in people younger than 75 who do not have a specific condition that negatively affects balance, regardless of whether they have an increased risk of falling [8]. Thus, the BBS may not be a good screening tool for this purpose and a more dynamic assessment may have been preferable. This limitation was not identified prior to testing.

B. Game Performance

Although the group mean BBS scores did not significantly change from weeks one to ten, the stepping game appears to be more sensitive to changes and can be used to isolate the contribution of the reaction time as compared to the step time as an indicator of cognitive processing. Improvements were found when analyzing response time, reaction time and step time data. However, the results from statistical analyses on these small groups cannot be extrapolated to a larger population. Reductions in response time and reaction time occurred in both the control and test groups in program B and in the test group in program A. This agrees with previous studies that show exercise can produce benefits with regards to improved sensorimotor function [18] and a reduced risk of falls [19]. The control group in program A, however, did not improve, suggesting that attendance at a program twice per week is more beneficial than once a week. This finding is further supported by the significantly decreased step time for participants in program B. There was also no difference in step times between control or test groups for either program suggesting that the effect of exercise is more significant to step time than the effect of the stepping game. It is important to note that the data from the control group in program A may be less reliable due to lack of attendance from two participants.

V. Conclusions

It is difficult to draw conclusions regarding the effect of the stepping game as this study is limited by the possible presence of a learning curve and the small group numbers. It was observed, especially in program A, that the participants had a much stronger grasp on the stepping game during the second use of the game. The control participants may have forgotten how to use the stepping game over the 10 weeks, resulting in an inaccurate representation of their progress. It may be more beneficial to investigate the progression of the test group data over the span of the experiment instead of attempting to draw conclusions in a pre- and post- intervention style. This study provided some pilot data that can be used to expand the evaluation or potentially prescribe this game to be used at-home for an extended, longitudinal timeframe.

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