Functional Balance and Dual-Task Reaction Times in Older Adults Are Improved by Virtual Reality and Biofeedback Training

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ABSTRACT

Virtual reality (VR) training has been used successfully to rehabilitate functional balance and mobility in both traumatic brain injury (TBI) survivors and elderly subjects. Similarly, computer-based biofeedback (BF) training has resulted in decreased sway during quiet stance and decreased reaction times during a dual-task reaction time paradigm in elderly subjects. The objective of this study was to determine the effect of VR and BF training on balance and reaction time in older adults. Two groups of twelve healthy older adults completed 10-week training programs consisting of two 30-min sessions per week. VR training required that participants lean sideways to juggle a virtual ball. Participants in the BF group viewed a red dot representing their center of gravity on a screen and were required to move the dot to the four corners of the monitor. Measures of functional balance and mobility (Community Balance and Mobility Scale [CB&M]), sway during quiet stance, and reaction time during a dual task paradigm were recorded before training, as well as 1 week and 1 month after the end of the program. Both groups showed significant improvements on the CB&M, as well as decreased reaction times with training. Postural sway during quiet stance did not change significantly.

INTRODUCTION

Physical activity has an important influence on health status, especially for seniors.1 Improving and maintaining functional abilities and balance is essential for seniors as falling can result in loss of independence, significant morbidity or death.2 Most seniors experience a loss of strength, bone density and balance that can lead to falls, loss of independence and reduced quality of life.3 Exercise can be used to slow, reduce and, in some cases stop these losses. Older adults can increase their strength, muscle mass and bone density with a strength training program.1 Unfortunately, various types of strength training result in little2,5 or no improvement6,7 in participant’s balance and among those showing an improvement in balance, only dynamic balance was significantly improved. Bellew et al.7 reported increased postural sway in older adults who completed a strength training program and suggested that increased muscular strength was not related to the ability to control sub-maximal isometric forces. Strength could be related to balance but a threshold seems to exist under which balance can be improved by a strength training program.8 According to Wolfson et al.,9 past this threshold, improvement in balance is possible but would require more specific training programs.

Specificity of training for balance has been demonstrated.9 After 15 weeks of balance training with biofeedback alone, strength training alone or a combination of both, participants receiving strength

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training improved their strength and participants who received balance training with biofeedback improved their balance. However, after the 6-month maintenance phase the balance training group’s scores for two of the three balance measures fell nearly back to baseline values.

In older adults, improvements in balance have been demonstrated following Tai Chi and visual biofeedback training. For example, 5 weeks of biofeedback training resulted in improved dynamic balance. A separate 15-week training program comparing the effect of Tai Chi and dynamic visual biofeedback training on the balance and the fear of falling of 48 older adults reported decreases in postural sway following biofeedback training but not Tai Chi. However, the fear of falling increased following biofeedback whereas the Tai Chi group reported a decreased in fear of falling compared their baseline data.

In contrast, Lajoie reported no change in either fear of falling or postural sway but found a significant decrease in reaction time following eight weeks of biofeedback training. Lajoie proposed that biofeedback training improved balance by decreasing the attention allocated to posture in favor of another task. Reaction time has already been suggested as a important variable of balance with simple reaction time identified as a primary factor to differentiate elderly fallers from elderly non-fallers.

Virtual reality is an emerging technology used for physical rehabilitation of different populations. Virtual reality is defined as a computerized simulation in two or three dimensions that is in real time and interactive. One of the benefits of virtual reality is the trainer’s ability to vary the environmental conditions and to give feedback. Another benefit is that virtual reality allows the trainee to simulate situations that would otherwise be dangerous, such as snowboarding to improve older adults’ balance. Under certain conditions and with specific tasks, greater learning has been demonstrated with training in virtual than physical environments.

We hypothesized that (1) functional balance and mobility of participants in both groups would improve with training and (2) the VR and BF groups would demonstrate improvements in dual task reaction time with no concomitant changes in postural sway.

METHODS

Participants and recruitment

The study was approved by the ethics committee at the University of Ottawa. A convenience sample of community-dwelling seniors who were over the age of 65, able to walk without an assistive device, and obtained a minimum of 20 on the Folstein Mini-Mental Exam for cognitive screening (to ensure comprehension of tasks and post-trial interview data) participated in the study. Exclusion criteria were one or more falls of unknown cause in the last year (i.e., not due to ice or illness), peripheral neuropathy, an uncontrolled heart problem, severe arthritis, severe back pain, a recent leg injury (last 6 months), tunnel vision, or any vestibular problem. Twenty-four subjects were divided into two equal groups (VR, 7 men and 5 women; mean age = 74.4, SD = 3.65 years; and BF, three men and nine women; mean age = 74.4, SD = 4.92).

Procedures

Participants completed a health questionnaire at baseline. Reaction time and balance were measured at baseline, and at 1 and 4 weeks after completion of the training program. At each evaluation, simple reaction time, static and dynamic balance, and functional abilities were examined for each participant.

Static balance. The anterior-posterior (A/P) and lateral (LAT) displacements of the foot center of pressure (COP) during quiet stance were computed from ground reaction forces recorded using a Kistler force plate. Three 1-min trials of three randomly ordered conditions were completed: (a) feet shoulder width apart; (b) feet together; and (c) feet together while performing a simple reaction time task. Participants were asked to remain motionless with the head straight and the arms on the side of the body. The root mean square (RMS) of A/P and LAT COP displacements were calculated and used as measures of postural steadiness.
Simple reaction time task. A dual task paradigm similar to the one used by Lajoie et al. was used. The primary task, quiet standing, required the participants to stand motionless with feet together on the force plate with the head straight and the hands at the side of the body. The secondary task required participants to say “top” when hearing an auditory cue. Six auditory cues were embedded in each one minute trial. Reaction time was defined as the time to respond without anticipation of a stimulus. Thus, to avoid anticipation, the auditory cues were initiated at 5–15-second intervals. Participants were instructed to concentrate on their posture and to respond as fast as possible without affecting their balance. Reaction time was coded as the delay between the auditory cue and production of the verbal response “top.”

Functional balance and mobility. The Community Balance and Mobility Scale (CB&M) is a performance-based measure developed for use with community-living adults who have sustained a mild to moderate TBI. The 13 items ranging from timed one-legged stance to descending eight steps carrying a laundry basket, measure postural instability in high-functioning ambulatory individuals. Test items were designed to reflect necessary skills for functioning well in the community. Test content and construct validity have been reported. The tool is currently undergoing further reliability and validity studies. A change of greater than 5 points is considered clinically significant and corresponds to a change in community integration and confidence in community mobility (J. Howe, personal communication, 2004). The test was administered using standardized instructions, and filmed and coded by a blinded research assistant.

Training protocol

Participants attended two 30-min sessions per week for a period of 10 weeks. During each session, participants completed 15 trials of 90 sec. During the first session, participants were asked to place their feet on a sheet of paper in a comfortable, near shoulder width position.

Dynamic balance training with visual biofeedback. Participants stood on a force platform with feet at shoulder width apart. A red cursor representing COP position in real time provided visual feedback on a monitor at eye level. Starting with the COP in the middle, participants were instructed to move the cursor to the four corners of a black rectangle. The cursor was brought back into the centre of the screen after reaching each corner. The cycle was completed in a clockwise and counter clockwise direction during each trial. Time remaining at the end of the trial was spent in quiet stance. Participants were told to bring the cursor as close as possible to each corner in a controlled matter.

Dynamic balance training in virtual reality. Participants in the VR group used one application, Juggler, from the computerized exercise program (IREX; www.irexonline.com). Subjects wore red gloves and stood in front of a monochrome wall (Fig. 1). A video camera captured the image of the subject, which was then sent to a computer-processing unit. Color subtraction software was used to remove the background from the video image and the isolated subject image was then combined with a virtual environment (VE). The subject viewed him/herself in the VE on a 29-inch television monitor and interacted in real-time (i.e., same time and speed as events in the real world) with virtual objects that appeared in the VE.

Standing with feet shoulder width apart, participants “juggled” a virtual ball falling at different distances from both sides of the body. Every time the participant touched the virtual ball, he was able to react to the trajectory of the ball as the ball bounced to the opposite or the same side. If a ball was missed, a new virtual ball was dropped randomly on either side. Participants reached laterally in a continuous movement without lifting their heels or bringing their hands over their shoulders and were asked to return their trunk back to the center after each reach attempt if they had time.

Statistical analysis

Descriptive statistics and frequencies were calculated using SPSS, version 11 (SPSS Inc., 444 Michigan Ave., Chicago, IL 60640) for appropriate demographic variables. Repeated-measures analyses of variance (ANOVA) were used to test for significant differences on the CB&M, LRT, and reaction time with factors Group (two levels), Gender (two levels), and Time (three levels). Repeated measures ANOVA were also used to test for significant differences in COP RMS with factors Group (two levels), Time (three levels), and Task (three levels). Subsequent pairwise comparisons were made using the Scheffé post-hoc test. All statistical analyses were completed using a p value of 0.05.
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RESULTS

Functional abilities

The mean CB&M scores for both groups increased significantly from baseline to post-training and retention ($F(2,46) = 14.5, p < 0.01$). The mean CB&M scores were 56.8, 62.5, and 63.9 for the BF group and 58.6, 64.2, and 64.7 for the VR group, for the baseline, post-training and retention test, respectively. The increases were greater than 5 points demonstrating clinically significant changes. There were no differences between groups ($F(1,23) = 0.163, p = 0.719$) nor was there a significant interaction effect ($F(2,46) = 0.263, p = 0.77$) indicating that both types of training improved functional balance and mobility similarly.

Static balance

There were no differences between groups and no training effect on variability of center of pressure displacement (COP RMS). However, a significant task effect ($F(2,44) = 101.91, p < 0.01$) and interaction between directions of sway and tasks ($F(2,44) = 73.52, p < 0.01$) was found (Fig. 2). A Scheffé test revealed that for both groups, the RMS$_{AP}$ and RMS$_{LAT}$ was significantly lower when the participants had their feet apart compared to RMS measures in both directions with feet together ($p < 0.01$). The RMS$_{AP}$ was significantly greater than the RMS$_{LAT}$ when participants had their feet shoulder width apart ($p < 0.01$). When participants had their feet together, the opposite was observed with the RMS$_{ML}$ significantly greater than the RMS$_{AP}$ ($p < 0.01$). No differences were found in RMS$_{AP}$ or RMS$_{LAT}$ with feet together between posture alone and dual-task. This suggests that the participants were concentrating on stabilizing posture during both tasks as instructed.

Reaction time

A two-way ANOVA (Group × Time) with repeated measures on the second factor revealed no group effect ($F(1,22) = 2.01, p > 0.05$) but a significant main effect of time ($F(2,44) = 10.30, p < 0.01$, Fig. 3). A Scheffé test showed that the reaction time at baseline was significantly higher ($p < 0.01$) compared to post-training and retention reaction time with no difference found between post-training and retention. No significant interaction between factors ($F(2,44) = 2.03, p > 0.05$) suggests that both
groups improved their reaction time equally after the training program and maintained the improvement after 1 month of completing their respective training programs.

**DISCUSSION**

After completing a 10-week training program either with visual biofeedback or virtual reality, older adults improved their functional balance and mobility as well as their reaction time during standing whereas postural sway during quiet stance did not change.

*Functional abilities*

The CB&M evaluates postural stability in a higher functioning population where participants need to perform more challenging activities while maintaining postural control in multitask situations and in sequence. An improvement in the CB&M scores indicates a higher level of postural control and consequently improved functional abilities.

Both groups increased their score on the CB&M test by 5 points indicating a statistically significant change due to training and, according to Inness and Howe,27 a clinically significant improvement. More importantly, the noted improvements persisted over

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**FIG. 2.** Group differences in root mean square means between axes for each postural sway conditions for virtual reality (A) and biofeedback (B).
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a period of 4 weeks showing the importance of the effects produced by the two training protocols. Participants’ improvements cannot be explained simply by traveling to the site of training because all participants were from day centers, therefore, used to traveling.

The two training program had quite different task demands. The biofeedback group needed to control their centre of pressure while reaching as far as possible to four different corners in a non-random manner. In contrast, the virtual reality group needed to hit a falling ball by reaching and shifting their body laterally. The distance the virtual reality group reached depended on the distance the ball was away from the body. Despite the different task demands of biofeedback and virtual reality, no difference was found in the CB&M score between groups suggesting the essence of both programs was similar. The biofeedback group had feedback concerning their centre of pressure and the virtual reality group had feedback relating to their body movement.

Postural sway

Postural sway represented by RMS scores was found to be different only between tasks. With feet apart, participants swayed more in the anterior-posterior axis compared to the medial lateral axis whereas during both tasks with feet together, participants swayed more in medial lateral axis compared to the anterior posterior axis. These differences were expected and follow a basic theoretical principle in balance: the amplitude of sway depends on the base of support. Importantly, there was no difference in RMS with feet together regardless of whether the auditory cue was present or not. This indicates that the participants’ followed the task instructions and concentrated on their posture. There was no change in RMS between or within either training group. Once again, this indicates training similarities but shows group similarities as well. This result suggests that the balance ability was similar within the two groups prior to the start of the training program and stayed similar throughout the study.

In contrast to Wolf et al., who reported increased postural sway with biofeedback training, the training completed in this study did not result in postural sway improvements for either group. The difference in training paradigms however may explain these findings. The biofeedback provided by Wolf et al. followed training with perturbations while subjects kept their eyes closed.

Our results concur with those of Lajoie, who reported no change in postural sway following 8 weeks of static biofeedback training (1 h twice per week). The RMS did not change after completion of the training programs, suggesting that the participants did not have any balance problems prior to the start of the training, thus, leaving little room for improvement.

Reaction time

The participant’s reaction times were shorter at post-training than at baseline. Since postural sway did not change, we propose that the attentional demands for the standing task must have decreased allowing participants to divert attentional resources to the reaction time task. This finding is in line with Lajoie’s works and supports his suggestions that completing a training program allows participants...
to improve their performance on the cognitive task because less attention is then needed for the postural task. Even after 4 weeks without training, participants had a faster reaction time compared to their baseline values demonstrating a retention effect. These data suggest seniors were able to automate a postural task as a result of biofeedback training and virtual reality training. Automating postural control is critical in an older adult’s life because seniors need more attention for any postural task as they get older. In fact, it has been demonstrated that reaction time is one of the most important factors to predict a fall. Since attention resources are limited, automating a task helps free the individual’s processing capacity to focus on other tasks. Therefore, it is possible to suggest that risk of falling might be lower after undergoing the training programs because seniors have more attention available to process external information and react faster.

CONCLUSION

Older adults can benefit from dynamic training with biofeedback and with virtual reality. This study showed that, with training, seniors were able to improve their functional abilities and reaction times, possibly due to allocating less attention to standing. The value of these training paradigms is possibly due to the concordance of visual and proprioceptive information during training, thus updating the way seniors perceive their body with their environment.

ACKNOWLEDGMENTS

We express gratitude to Francis MacDougall of IREX who provided software modifications for the virtual reality balance training sessions, to the Good Companion Seniors’ Centre for their warm hospitality, and to Shane Smith for assistance with data acquisition. The study was funded, in part, through an NSERC Canada research grant and by the Ministry of Economic Development and Trade (Ontario). H.S. is a Career Scientist with the Ministry of Health and Longterm Care of Ontario.

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