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Treadmill Training with Virtual Reality to Decrease Risk of Falls in Idiopathic Fallers: A pilot Study

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Abstract— Falls in the elderly are a major health problem affecting a third of the elderly over the age of 65. Numerous fall prevention interventions have been suggested but to date, the content of the optimal exercise program as well as its optimal duration and intensity have not yet been established. The Aim of this pilot study was to investigate whether Virtual Reality can be applied to address the multifaceted deficits associated with fall risk in the elderly. Five elderly women (67.1 ± 6.5 years) with a history of falls received 18 sessions (3 per week x 6 weeks) of progressive intensive treadmill training with virtual obstacles (TT + VR) consisting of obstacle navigation. Post-training, gait speed significantly improved during usual walking, dual tasking and while negotiating over-ground obstacles. Dual task cost and over-ground obstacle clearance also improved. TT + VR may be feasible for gait training of elderly fallers and may improve physical performance, gait during complex challenging conditions. Effects of training on fall frequency are still to be determined.

Keywords-Virtual-Reality, Idiopathic Fallers, Gait, Fall Prevention

I. Introduction

Falls in the elderly are a major health problem. Approximately 30% of community-dwelling elderly over the age of 65 fall at least once a year and 6% of these falls result in fractures [1]. Besides the physical injuries, falls may lead to fear of falling, depression and social isolation [2]. Between 30% and 73% of older persons who have fallen acknowledge a fear of falling [3-5] which can results in self- imposed activity restrictions among home living elderly fallers and loss of confidence in the ability to walk safely which causes further functional decline [6]. Three main reasons for falls have been identified: 1) falls resulting from gait and balance impairments, 2) falls resulting from tripping over an obstacle, and 3) falls resulting from inattention or when divided attention is impaired. These situations often occur during daily activities when walking while performing a simultaneous task (i.e., dual tasking). Numerous fall prevention interventions have been suggested but to date, the content of the optimal exercise program as well as its optimal duration and intensity have not yet been established [7;8].

VR can provide auditory and haptic inputs that require cognitive processing while simultaneously allowing for motor training. Theoretically, this multisensory feedback enhances motor learning through problem solving, while promoting the performance of multiple repetitions of movement. VR-based training in the post-stroke population has shown encouraging results for improving gait speed, endurance, and force production [9;10] and for addressing cognitive deficits [11]. Similarly in elderly patients with Parkinson's disease, training with VR has shown improvements in dual task performance and obstacle negotiation even up to 1 month post training [12]. The objectives of the present study were to investigate the feasibility of using TT + VR for training of idiopathic fallers and to examine the effectiveness of TT + VR for improving gait, Dual Task (DT) abilities, and obstacle negotiation, known mediators of fall risk as well as assessing the effects of training with VR on fall frequency.

II. Methods

A. Participants

Five idiopathic elderly fallers participated in this study (mean age 67.1 ± 6.5 years) All subjects were females; independent in activities of daily living, independent in walking short distances but had sustained at least 2 falls in the 6 months prior to the beginning of the study. Subjects were cognitively intact (mean MOCA score 25.6±2.8), had no neurological or orthopedic disorders that could affect their gait, or severe visual or hearing impairments. All subjects signed an informed consent prior to the beginning of the study.

B. Procedures

A repeated measures design (pre training, post training, and follow-up at 4 weeks, 3 month and 6 months post intervention) was used. Subjects were asked to walk in a well-lit corridor under three conditions each of 1 minute: (i) walk at comfortable speed, (ii) walking while performing serial 3 subtractions from a predefined number (DT), (iii) walking while negotiating two obstacles (box: 50 cm W × 30 cm D × 40 cm H and lines: 50 cm W × 40 cm D apart) placed on the floor at specific locations. The 6-minute walk test was used to assess endurance measured as the total distance walked in 6 minutes .

The GaitRite mat, a sensorized 7 m carpet (CIR Systems, Inc., Haverton MA), quantified spatial features of gait, such as stride length. Over-ground obstacle negotiation was evaluated by step length and effective obstacle clearance. The physical obstacles (see earlier) were placed on the GaitRite. The distance between the heel and the physical obstacle during the

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loading response of the lead foot was measured to assess clearance and efficient obstacle negotiation. The Timed Up and Go (TUG) test and was used to assess functional mobility and dynamic balance. The Four Square Step Test (FSST) assessed over-ground obstacle negotiation, dynamic balance, and fall risk. The Montreal Cognitive Assessment characterized baseline cognitive function, and the Trail Making Test (TMT; color version) was used to assess the effects of the intervention on cognitive function. The TMT A evaluates scanning ability and upper extremity motor function, and TMT B evaluates set shifting, an aspect of Executive function (EF) that has been previously related to mediators of fall risk and future falls [13;14]. Performance on the DT activities was evaluated based on the number of subtractions made, the number of errors made, and the DT cost, a measure that reflects the effect of the second task on gait ability, as compared with baseline walking, that is, DT cost = 100 × (single-task gait speed – DT gait speed)/single-task gait speed. A fall was defined as unintentionally coming to rest on a lower surface. Fall frequency, was assessed over half a year both retrospectively at baseline (to evaluate previous risk) and prospectively (to evaluate the effects of training) using: 1) a 'falls questionnaire', and 2) Monthly calendar. Each calendar was labeled with the specific dates and holidays of the particular month. Subjects were asked to report falls on the calendar, completed daily. The calendars were returned to the laboratory by mail using prepaid and pre-addressed envelopes. Subjects were contacted by telephone if the calendar was not returned in a timely manner, or if the calendar was completed incorrectly.

C. *Intervention*

Participants walked on the treadmill with a safety harness that prevented falls but did not provide body weight support. Two light emitting diodes (LED's) were connected to the subject's shoes on the lateral side. These LED's served as the interface to the simulation which was projected on the screen in front of the treadmill. The simulation consisted of an outdoor environment with different obstacles. The VR simulation required the participants to process multiple stimuli simultaneously and challenged them to make decisions about obstacle negotiation in two planes, while continuing to walk on the treadmill. The virtual obstacles were in two dimensions (vertical to increase step clearance and horizontal to increase step length). The speed, orientation, size, frequency of appearance, and shape of the targets were manipulated according to individual needs following a standardized protocol. This protocol was designed to achieve a success rate of 80% in clearing the obstacles to promote engagement and motor learning. The virtual environment imposed a cognitive load that demanded attention, response selection, and the processing of rich visual stimuli involving several perceptual processes (see Figure 1). The intervention lasted 6 weeks (three sessions per week). Training progression was based on an earlier study protocol of intensive progressive individualized TT+VR in patients with PD[15]. Each training session lasted about 45 minutes and started with 5 minutes of "warm up" (only walking on the treadmill). After each warm-up phase, the VR simulation was introduced. The duration of continuous walking before rest breaks (typically three to five minutes initially) and the total walking time were also increased throughout the sessions. Feedback was given to the participant in the form of knowledge of results as a measure of scoring on the obstacle avoidance tasks and knowledge of performance in the form of auditory and visual feedback if the subject contacted a (virtual) obstacle.

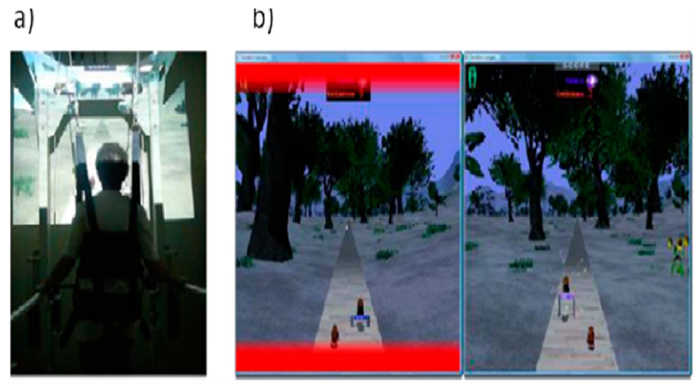

Figure 1. The virtual reality system is used in this study. To light-emitting-diodes (LED) were attached to the lateral side of each participant's usual shoes to tract movement of the foot. (a) A participant walking on the treadmill with the safety harness (without body weight support) while viewing the virtual environment. (b) The outdoor virtual environment. Sample feedback can be seen (e.g. Red bars: negative feedback and lights in the picture: positive feedback).

D. *Data Analysis*

In this pilot study, data was examined for normalcy and descriptive statistics were extracted for all clinical, gait and cognitive measures. Data was compared across time.

III. RESULTS

Subjects' characteristics are presented in table 1. All participants completed the training. The average net training time in the initial session was 17.8±1.1 minutes; total training time increased to 43±6.9 minutes in the last session with an average of 515± 60.5 cumulative minutes walked. At the conclusion of the training participants reported enjoyment and high satisfaction from the training as obtained by the Quebec User Evaluation of satisfaction with Assistive Technology Questionnaire (QUEST). Four out of the 5 patients wanted to continue the training and reported that they felt an improvement in their sense of security when walking outdoors in the city streets.

Gait measures

Gait speed during usual walking increased by 8.9% (from an average of 112.6±9.3 to 122.02±7.9 m/s) after training. Gait speed during dual tasking (serial 3 subtractions) improved by 9.9% (from an average of 102.4±7.4 to 112.02±8.8 m/s) after training stride length during the dual task condition increased by 6.6% after training. Gait speed during obstacle negotiation improved by 26.9% (from an average of 85.7±16.6 to

105.4±3.9m/s) after training. Stride length in the obstacle condition also improved by 20.8% (from an average of 105.3 ±14.4 to 125.1± 8.3m/s). Endurance, as measured by the distance walked during 6 minutes (6MWT), improved after training by a mean of 9.5% amounting to an increase of 60 meters. A decrease of 20.8% was observed in the time to perform the TUG. Performance time on the FSST improved by 17% after training.

Table 1: Subjects characters

Patient	1	2	3	4	5
Age (y)	80	79	70	73	76
Gender	female	female	female	female	female
MoCA (max 30)	23	30	24	27	24
Falls*	2	5	2	3	2

*Number of falls in the 6 month prior to the intervention.

Obstacle negotiation

Obstacle clearance improved by the mean of 50.97%. The distance from the vertical obstacle to the led foot heel strike increased from an average of 13.8cm±4.8 pre training to 18.5cm ±2.7 post training.

Dual task Performance

Dual task cost after training improved by a staggering mean of 126.6%. Improvements were also observed in the average time to complete the TMT (part A) by 19.6%, reflecting improved scanning abilities

Fall Frequency

Fall frequency was assessed using fall calendars and a falls questionnaire for 6 months post training. At the time of submission of this paper, two subjects have completed 4 month follow up evaluation with 1 subject reporting 1 fall within 3 months and the others had no falls. Data on fall frequency will be added once all subjects completed the 6 month follow up.

IV. Discussion

This pilot study demonstrated the feasibility of training elderly subjects with a combined treadmill-VR system. After 6 weeks of intensive training, improvement in gait speed and stride length were observed under usual and dual tasking conditions as well as improvement in endurance, and functional ability (as seen by the performance on the TUG and FSST). Interestingly before training stride length in the obstacle and DT conditions were shortened due to the difficulty in walking while attending to another task. After training with the VR stride length improved dramatically in the obstacle and DT conditions and became closer to that observed under usual gait condition, suggesting a heightened ability to perform DT activities.

These findings were corroborated also by the large decrease (improvement) in the DT cost, expressed by the change in gait speed between usual and DT conditions. This cost is often referred to as a measure of the ability of the individual to allocate attention to different simultaneous tasks. Attentional reserves are often reduced with aging placing older adults at a heightened risk of falling when they attempt to perform two or more tasks simultaneously, even if the tasks are otherwise considered to be automatic or demand minimal attention [15]. Numerous studies have shown that dual task effects are larger among fallers than the general elderly population and patients with neurological disease like stroke, Alzheimer's or Parkinson's [17-19]. Therefore enhancing DT ability can therefore reduce the risk of falls.

All subjects demonstrated improved performance on the TMT (part a). This section relates to scanning. During the training patients were required to scan the virtual environment to identify obstacles and distracters that could hinder performance. The change in the TMT therefore is related to the practice itself. Anstey et al. [8] found that slower performance on the TMT was associated with risk of major injury due to non-syncopal falls. Therefore this finding provides yet another indication that this form of training can assist in improving both motor and cognitive function and perhaps decrease the risk of falls.

At the time of submission of this paper, data on the effects of training on fall frequency is not available. Data will be provided as soon as the follow up evaluations are completed. We are confident that the training created a behavioral change that was induced by learning new strategies of obstacle negotiation and enhanced cognitive abilities which resulted in improved performance and may consequently demonstrate a decrease in the risk of falls.

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