Improved mobility and reduced fall risk in older adults after five weeks of virtual reality training

S R Shema[1], P Bezalel[1], Z Sberlo[1], O Wachsler Yannai [2], N Giladi[1,3,4], J M Hausdorff[1,4,5,6], A Mirelman[1]

[1]Laboratory for Gait and Neurodynamics, [2]Department of Physical Therapy, Tel Aviv Sourasky Medical Center, Tel-Aviv, ISRAEL

[3]Sackler Faculty of Medicine, [4]Sagol School of Neuroscience, [5]Department of Physical Therapy, Tel-Aviv University, Tel-Aviv, ISRAEL

[6]Harvard Medical School, Boston, MA, USA

[1]*shirleys@tlvmc.gov.il*, [2]*anatmi@tlvmc.gov.il*

[1]*www.tasmc.org.il*

ABSTRACT

The aim of this analysis was to assess whether 5 weeks of training with virtual reality (VR) in a clinical setting can reduce the risk of falls in a variety of older adults. Thirty-four participants attending the VR clinic were studied. Participants underwent 15 training sessions consisting of walking on a treadmill with a VR simulation. Significant improvements were observed in gait speed, the Four Square Step Test and the Timed Up and Go. Treadmill training with VR appears to be an effective and practical clinical tool to improve mobility and reduce fall risk in older adults.

1. INTRODUCTION

Normal and safe mobility depends on intact sensory and motor systems, but there is a growing body of research that specifically links the cognitive sub-domains of attention and executive function (EF) to gait alterations and fall risk (Springer et al, 2006; Yogev-Seligmann et al, 2008). EF apparently plays a critical role in the regulation of gait especially under challenging conditions where decisions need to be made in real-time and constant adaptation is required to manage internal and external factors (Ble et al, 2005). External factors can include, for example, obstacle crossing or attending to multiple tasks during walking. The performance during more demanding daily activities, such as walking while performing a simultaneous task (i.e., dual or multi task) or obstacle negotiation, plays a key role in the safety and well-being of a variety of individuals with either motor and cognitive dysfunctions (Beauchet et al, 2005; Shumway-Cook and Woollacott, 2000). Thus, interventions which focus on a combined motor-cognitive approach may improve gait and decrease the risk of falls.

Previous studies on the use of VR for training of balance, gait and fall risk in older adults and individuals with neurological disorders have shown positive effects on walking speed, stride time and step length as well as in the ability to perform dual task and obstacle negotiation as compared to training in conventional balance training groups (Buccello-Stout et al, 2008; de Bruin et al, 2010; Mirelman et al, 2010). Studies have also shown improved dual task ability and cognitive function after the use of motor-cognitive rehabilitation using VR (Mirelman et al, 2011a; Mirelman et al, 2011b). Recently we have also shown positive effects of using VR as a clinical service (Shema et al, 2014). The effects of VR on the risk of falls in older adults are unknown.

The ‘Timed Up and Go’ test (TUG) (Podsiadlo and Richardson, 1991) is a quick and widely used performance-based measure of mobility. The TUG has been extensively studied in older adults (Hatch et al. 2003;Shumway-Cook et al. 2000) and recommended as a simple screening test of fall risk. TUG duration has also been associated with cognitive function (Donoghue et al, 2012a; Herman et al, 2010). More specifically, older adults with better executive function and attention performed the TUG more quickly (Donoghue et al, 2012b; Herman, Giladi and Hausdorff, 2010). Previous work has demonstrated the added value of using body-worn sensors to augment the traditional TUG (Mirelman et al, 2014). Thus the aim of this analysis was to assess whether 5 weeks of training with VR in a clinical setting can reduce the risk of falls as measured using the instrumented TUG and other tests of mobility in a variety of older adults with gait impairments.

2. METHODS

2.1 Participants

The current retrospective data analysis reviewed the medical records of 34 participants (mean age 74.51 ± 10.51 years, 56% women) attending a gait rehabilitation program at the VR clinic in the Tel Aviv Sourasky Medical Center. The study was approved by the local institutional human studies committee. All participants were referred to the clinic by their physicians. Indications for referral included recurrent falls, fear of falling, complaints of gait instability or recent deterioration of gait, mainly but not exclusively due to neurological etiology. Participants were eligible for the training program if they were: 1) able to walk independently for at least 5 minutes with or without walking aids; 2) did not have any cardiac contra-indication for moderate training intensity; and 3) did not have severe visual loss that could interfere with their ability to see the VR simulation. Participants who could not follow simple instructions and those with dementia (as per DSM IV guidelines) or diagnosed psychiatric disorders were not eligible for the training program.

2.2 Training

Training was provided 3 times per week for 5 weeks with each session lasting about one hour. During the training, patients walked on a treadmill with a safety harness which did not provide body weight support. Two light emitting diodes (LEDs) were attached to the lateral side of the patients' shoes which served as the interface to the VR simulation that was projected on a screen in front of the treadmill. The virtual environment (VE) simulation included an obstacle course situated along different pathways in an outdoor scene. The various pathways differed in duration, number of intersections, and challenging segments which included bifurcations and walking on a bridge over a river. The virtual obstacles required negotiation in two planes: 1) vertical, to increase step clearance and 2) horizontal, to increase step length (see Figure 1). Difficulty levels were graded based on obstacle size and frequency of appearance as well as time of appearance requiring the participants to plan ahead, adapt their steps and select the correct negotiation strategy to avoid a collision. Feedback was provided by the simulation and consisted of knowledge of performance and knowledge of results. Training parameters were gradually increased from week 1 to week 5. Motor load was increased by adapting the treadmill speed, prolonging walking duration and decreasing the participants' hand support on the treadmill bars while walking. The VE parameters were progressed by presenting a wider range of obstacle sizes, increasing obstacle frequency of appearance, disrupting visual clarity and the addition of virtual distracters. Cognitive load progression was achieved by challenging sustained and divided attention, planning and reaction time.

Figure 1. *Two types of virtual obstacles were used, requiring patients to adjust proper step length and step clearance.*

2.3 Clinical Evaluation and Assessment

Gait speed was assessed before and after the training by measuring the time walk 10 meters. Obstacle negotiation was assessed using the Four Square Step Test (FSST). The instrumented Timed Up and Go (TUG) test was used to evaluate functional mobility, dynamic balance and fall risk (Shumway-Cook, Brauer and Woollacott, 2000). Participants wore a small, portable, light-weight body-fixed sensor (DynaPort, McRoberts BV, The Hague, the Netherlands) on their lower back secured using a neoprene belt. The sensor includes a triaxial accelerometer and gyroscope. Acceleration signals were derived from three axes: vertical, mediolateral, and anterior posterior. Angular velocities were derived from the gyroscope as yaw (rotation around the vertical axis), pitch (rotation around the mediolateral axis), and roll (rotation around the anterior-posterior axis). After testing was completed, data were transferred to a personal computer for further analysis. The TUG subtasks (sit-to-stand and stand-to-sit transitions, walking, and turning) were analyzed using an automated algorithm based on the anterior-posterior axis that was used for detecting the start and end times of the TUG (Weiss et al, 2011).

2.4 Data Analysis

Data was examined for normality and descriptive statistics were extracted for all clinical measures. Data was compared across time (i.e., before vs. after the 5 weeks of training) using paired t-tests or Wilcoxon Signed Rank test, as appropriate. Analyses were performed using SPSS version 21 with an alpha level of 0.05.

3. RESULTS

All participants finished all 15 sessions of training. No adverse events were reported. All subjects had a history of falls (mean 2.82 ± 4.16 falls in the 6 months prior to the study) and demonstrated a high risk of falls as reflected by the TUG pre-training (18.53 ± 9.08 sec). Gait speed improved after training (0.97 ± 0.26 m/s to 1.03 ± 0.28; p=0.025). Similarly, dynamic balance and obstacle negotiation (FSST) improved after training by 14% (from 17.34±6.77 sec to 14.92±4.99 sec; p=0.014).

Time to complete the TUG significantly improved demonstrating a decrease in fall risk (18.53 ± 9.08 sec to 16.77 ± 7.63 sec; p=0.008). Analysis of the subtasks of the instrumented TUG demonstrated that improvements in TUG duration stem from faster walking speed during the walking subtask of the TUG (10.5 ± 6.07 sec vs. 9.48 ± 5.57 sec; p=0.019), with decreased number of steps taken (20 ± 13.48 vs. 17.38 ± 11.61; p=0.009). In addition, the duration of the turn-to-sit was reduced after training (2.38 ± 0.89 sec vs. 2.12 ± 0.62 sec; p=0.043), reflecting lower angular velocity during the turns.

4. CONCLUSIONS

The study demonstrates that after 5 weeks of intensive treadmill training with VR, the participants preformed the TUG and the FSST faster, suggesting improved functional mobility. The improvements observed in after training further reflect an important decrease in the risk of falls at a group level. The use of wearable sensors to quantify the TUG and its subtasks provided insights into gait performance and the specific effects of the VR training. The results demonstrated that the subjects walked faster with an increased step length as reflected by the decreased number of steps taken. This finding is directly related to the trained tasks and demonstrated transfer of training effects. However, the results also revealed additional benefits in dynamic stability and planning as observed by the reduced turn duration.

Training with VR differs from usual gait training, as it contains cognitive aspects of planning, constant adaptation and shifting of attention under challenging motor conditions. As a combined approach, it promotes motor learning through problem solving, thus enhancing executive. The TUG and FSST present short yet relatively complex motor-cognitive tasks, demanding rapid changes in body alignment (i.e., turns or step direction) while maintaining balance. These tests are associated with cognitive processes, since they require subjects to remember and execute a timed motor sequence, involving motor planning and shifting, attributes that are needed for maintaining safe gait in daily living. Thus the present findings suggest that training with VR can promote both motor and cognitive function that can transfer to daily living activities and promote health.

We believe that the use of different virtual obstacles promoted greater clearance and increased step length contributing to the improved gait pattern. The virtual environment enabled a challenging training in a functional context, while maintaining patient safety which is valuable for the patient and the trainer. The ecological validity of the virtual simulation promoted motor learning as well as transfer of gains into real world performance. The findings suggest that after training, participants had better functional mobility and had decreased risk of falls. The study further demonstrates the utility of VR in a clinical setting in improving functional abilities and gait performance in a variety of older adults. A future analysis of a larger cohort, including subjects with additional musculoskeletal pathologies, may help to identify further indications for this program.

Acknowledgements: We would like to thank the participants of this study as well as Eran Gazit, Inbal Maidan, Moran Dorfman, Lior Yeshaayahu, Ricki Turgeman for their assistance in this study. This research was supported in part by the European Commission (FP7 project V-TIME- 278169) and by the Tel Aviv Sourasky Medical Center Grant of Excellence.

5. REFERENCES

Beauchet, O, Dubost, V, Herrmann, F, Rabilloud, M, Gonthier, R, and Kressig, RW, (2005), Relationship between dual-task related gait changes and intrinsic risk factors for falls among transitional frail older adults, *Aging Clin.Exp.Res.*, 17, (4) 270-275 available from: PM:16285191

Ble, A, Volpato, S, Zuliani, G, Guralnik, JM, Bandinelli, S, Lauretani, F, Bartali, B, Maraldi, C, Fellin, R, and Ferrucci, L, (2005), Executive function correlates with walking speed in older persons: the InCHIANTI study, *J.Am.Geriatr.Soc.*, 53, (3) 410-415 available from: PM:15743282

Buccello-Stout, RR, Bloomberg, JJ, Cohen, HS, Whorton, EB, Weaver, GD, and Cromwell, RL, (2008), Effects of sensorimotor adaptation training on functional mobility in older adults, *J.Gerontol.B Psychol.Sci.Soc.Sci.*, 63, (5) 295-300 available from: PM:18818444

de Bruin, ED, Schoene, D, Pichierri, G, and Smith, ST, (2010), Use of virtual reality technique for the training of motor control in the elderly. Some theoretical considerations, *Z.Gerontol.Geriatr.*, 43, (4) 229-234 available from: PM:20814798

Donoghue, OA, Horgan, NF, Savva, GM, Cronin, H, O'Regan, C, and Kenny, RA, (2012a), Association between timed up-and-go and memory, executive function, and processing speed, *J.Am.Geriatr.Soc.*, 60, (9) 1681-1686 available from: PM:22985141

Donoghue, OA, Horgan, NF, Savva, GM, Cronin, H, O'Regan, C, and Kenny, RA, (2012b), Association between timed up-and-go and memory, executive function, and processing speed, *J.Am.Geriatr.Soc.*, 60, (9) 1681-1686 available from: PM:22985141

Hatch, J, Gill-Body, KM, and Portney, LG, (2003), Determinants of balance confidence in community-dwelling elderly people. *Phys Ther.*, 83, (12) 1072-1079 available from: PM:14640866

Herman, T, Giladi, N, and Hausdorff, JM, (2010, Properties of the 'Timed Up and Go' test: more than meets the eye, *Gerontology* available from: PM:20484884

Mirelman, A, Maidan, I, Herman, T, Deutsch, JE, Giladi, N, and Hausdorff, JM, (2011a), Virtual reality for gait training: can it induce motor learning to enhance complex walking and reduce fall risk in patients with Parkinson's disease?, *J.Gerontol.A Biol.Sci.Med.Sci.*, 66, (2) 234-240 available from: PM:21106702

Mirelman, A, Patritti, BL, Bonato, P, and Deutsch, JE, (2010), Effects of virtual reality training on gait biomechanics of individuals post-stroke, *Gait.Posture.*, 31, (4) 433-437 available from: PM:20189810

Mirelman, A, Raphaely-Beer , N, Dorffman , M, Brozgol , M, and Hausdorff, JM, (2011b), Treadmill training with Virtual Reality to decrease risk of falls in idiopathic fallers: A pilot Study, *In International Conference on Virtual Rehabilitation*, pp. 1-4.

Mirelman, A, Weiss, A, Buchman, AS, Bennett, DA, Giladi, N, and Hausdorff, JM, (2014), Association between performance on Timed Up and Go subtasks and mild cognitive impairment: further insights into the links between cognitive and motor function, *J Am Geriatr Soc*, 62, (4) 673-678 available from: PM:24635699

Podsiadlo, D, and Richardson, S, (1991), The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J.Am.Geriatr.Soc.*, 39, (2) 142-148 available from: PM:1991946

Shema, SR, Brozgol, M, Dorfman, M, Maidan, I, Sharaby-Yeshayahu, L, Malik-Kozuch, H, Wachsler, Y.O, Giladi, N, Hausdorff, J.M, and Mirelman, A, (2014), Clinical Experience Using a 5-Week Treadmill Training Program With Virtual Reality to Enhance Gait in an Ambulatory Physical Therapy Service, *Phys.Ther.* available from: PM:24786944

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, *Phys.Ther.*, 80, (9) 896-903 available from: PM:10960937

Shumway-Cook, A, and Woollacott, M, (2000), Attentional demands and postural control: the effect of sensory context, *J.Gerontol.A Biol.Sci.Med.Sci.*, 55, (1) M10-M16 available from: PM:10719767

Springer, S, Giladi, N, Peretz, C, Yogev, G, Simon, ES, and Hausdorff, JM, (2006), Dual-tasking effects on gait variability: the role of aging, falls, and executive function, *Mov Disord.*, 21, (7) 950-957 available from: PM:16541455

Weiss, A, Herman, T, Plotnik, M, Brozgol, M, Giladi, N, and Hausdorff, JM, (2011), An instrumented timed up and go: the added value of an accelerometer for identifying fall risk in idiopathic fallers, *Physiol Meas.*, 32, (12) 2003-2018 available from: PM:22094550

Yogev-Seligmann, G, Hausdorff, JM, and Giladi, N, (2008), The role of executive function and attention in gait, *Mov Disord.*, 23, (3) 329-342 available from: PM:18058946