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EVALUATION OF A VIRTUAL REALITY BASED BALANCE TRAINING PROGRAM IN INDIVIDUALS WITH MILD COGNITIVE IMPAIRMENT

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ABSTRACT:

Mild cognitive impairment (MCI) is characterized by not only a decline in cognition and executive function but also motor function and coordination as defined by gait and balance. In order to assess the effectiveness of existing virtual reality based balance training on motor performance, this study randomized a subset of patients at Banner Sun Health Research Institute to balance training intervention (n=12) or control (n=10) groups. Using wearable sensors, participants in the intervention group received 8 training sessions, on average twice a week for 4 weeks, during which they were asked to perform both weight-shifting and obstacle-crossing tasks. Center of mass, ankle, and hip sway measurements as well as normal and fast walking speeds were used to assess balance and gait respectively. Secondary outcome measures included trail making A and B tests to assess cognition, along with fear of falling and depressive sign scales to assess psychosocial factors. The intervention demonstrated effects on reduction of center of mass, ankle, and hip sway (p=0.015-0.041) as well as a reduction in fear of falling (p=0.015) in intervention group participants as compared to the control group. These results suggest that virtual reality based balance training can improve balance in patients with MCI and that such interventions have the potential to mitigate aspects of motor performance decline within this population.

INTRODUCTION:

Worldwide, trends of increased life expectancy and decreased fertility have resulted in the growing proportion of those aged 60 years or older. According to the United States Census Bureau,[1] 13.0% of the population (40.3 million individuals) are aged 65 years and older, with a projected increase to 20.9% by the year 2050. With the rapid growth of older cohorts, the prevalence of chronic health conditions such as Alzheimer's Disease is also estimated to increase,[2] with world-wide projections of dementia prevalence doubling approximately every 20 years.[3]

Dementia is defined by a group of symptoms linked to cognitive impairment and is characterized by advancing age as a major risk factor.[4] At the global level, the prevalence of dementia in adults 60 years and older ranged from 5-7%, with an estimated total of 35.6 million individuals living with dementia in 2010.[5] While the symptoms of mild cognitive impairment (MCI) are not as severe as dementia, it has been shown that it is a more prevalent condition and that those with MCI have a high risk of developing dementia.[6]

Mild cognitive impairment is defined as the transition stage between cognitive decline associated with aging and the more severe dementia, with symptoms including difficulties with memory, language, attention[7] as well as deficits in executive functioning, defined as the coordination of complex cognitive processes to include activities such as task-switching and planning.[8] While the specific criteria continue to be disputed,[9] MCI is currently defined as a deficit in at least one cognitive domain as indicated by the DSM-5. These include learning and memory, language, executive function, complex attention, perceptual-motor function, and social cognition without dementia or impairment of activities of daily living. Similarly, while the prevalence of MCI differs between the criteria used to define the condition,[10] the worldwide prevalence has been shown to fall between 14-18% in populations aged 70 years and older.[11] Studies have indicated conversion rates of approximately 10% of those with MCI to dementia.[12] As noted, MCI has been identified as a risk factor to progression to the more severe cognitive impairment of dementia, predominantly caused by Alzheimer's disease and other neurological conditions.[6] In their review, Gauthier et al. note an especially high rate of the progression of the amnestic subtype of MCI, the most common subtype of the condition, to Alzheimer's disease from 16% per year up to 41% per year depending on the baseline characteristics of the population.[13] Consequently, MCI has been suggested as a potential indicator and target for addressing the issue of dementia,[11,14] a condition that is becoming more prevalent with the increasing proportion of the elderly population.

In addition to the increased risk of progression to dementia, MCI has implications on physical functioning to result in increased balance problems.[15] Studies have also found an association between MCI and impairments in executive function,[16] indicating difficulties with managing cognitive processes and potential dangers in task-shifting or dual-tasking to further increase fall risk.

Reviews of previous studies have found efficacy of computer-based training in improvement of physical functioning in older adults with neurological impairments representative of the cognitive impairments seen in aging[17] as well as better cognitive outcomes than traditional approaches in healthy adults[18] and better dual-task reaction times.[19] The virtual reality component of these trainings is a powerful tool in maintaining physical activity in elderly populations while allowing for the manipulation of environmental cues in a safe space for these individuals.[20] Finally, with the relative lack of research on the effects of virtual reality training in patients with MCI, this project aims to elucidate the applicability and efficacy of virtual reality based technology on the given patient population.

The objective of the project was to pilot test an existing virtual-reality based balance training technology in patients with mild cognitive impairment. Individuals identified by healthcare workers at Banner Sun Research Institute were recruited and presented with the background of the technology and its applications. Baseline and follow-up assessments were completed through a series of questionnaires as well as balance and gait measurements. Those randomized to the intervention group participated in balance training exercises based on two parameters, ankle sway exercises and obstacle training, as a means by which to improve balance. Planned outcomes included validation and evaluation of the program to build on and improve this existing technology in addition to assessment of the effectiveness of the program on improving gait and balance as well as cognitive and psychosocial outcomes. Finally, the project served to integrate the expertise of various research institutions within Arizona and facilitated collaboration between researchers from different regions and fields.

As such, the study aims primarily to address the impact of virtual reality training based on weight-shifting and obstacle crossing exercises on the primary outcome of balance and gait in patients who have been diagnosed with MCI.

Hypothesis 1—balance & gait: It is hypothesized that virtual reality based balance training will improve balance and gait measurements of individuals diagnosed with MCI (H_1). Alternatively, that virtual reality based balance training will have no effect on MCI patients (H_o).

Objective 1: To determine the effect of virtual reality based exercise on balance measured at different anatomical locations: (1) center of mass, (2) ankle sway, and (3) hip sway.

Objective 2: To determine the effects of virtual reality based exercise on gait as measured by sensor data when patients are asked to perform (1) normal walk and (2) fast walk.

While not directly influenced by the intervention, secondary outcomes of interest include cognition and psychosocial assessments that are associated with diagnosis of MCI.

Hypothesis 2—cognition & psychosocial: It is hypothesized that virtual reality based balance training will improve cognition and psychosocial measurements of individuals diagnosed with MCI (H_1). Alternatively, that virtual reality based balance training will have no effect on MCI patients (H_o).

Objective 3: To determine the effect of virtual reality based exercise on cognition, indicated by speed in performing (1) Trail Making A and (2) Trail Making B tasks.

Objective 4: To determine the effect of virtual reality based exercise on cognition, indicated by results on (1) Fear of Falling assessment and (2) Depressive Signs scale.

MATERIALS & METHODS:

The sponsoring site of the project was Banner Sun Health Research Institute, a center devoted to the study of the diseases of aging located in Sun City, AZ, a community with over 100,000 residents above the age of 65. With resources and ongoing research in various chronic disease topics, Banner Sun Health Research Institute served as an appropriate site to effectively study and assess the computer-based combined motor-cognition training in improving balance control as well as executive function in a patient population with mild cognitive impairment.

A randomized control trial was performed with participants randomized to the intervention group receiving virtual reality training on average twice a week for 4 weeks and the control group receiving no intervention. Baseline measurements were taken for both groups with follow-up measurements completed approximately 4 weeks after the initial screening. Participants aged 65 years or older who were diagnosed with MCI and able to walk at least 20 meters without assistance were recruited from Banner Sun Health Research Institute in Sun City, Arizona. The exclusion criteria included diagnosis of dementia or Parkinson's disease, major mobility disorder, or stroke within the past 6 months.

Various measurement tools were used during the study including questionnaires, Short Falls Efficacy Scale and Center of Epidemiological Studies Depression Scale (CES-D), and data collected from the LegSys+ sensors. LegSys+ was the wearable technology system implemented in the study's virtual reality training paradigm, consisting of 5 sensors, 1 on the lower back, 2 on the thighs (left and right), and 2 on the shanks (left and right). Center of mass sway was measured by area, anteroposterior sway, mediolateral sway (in centimeters) while ankle and waist motion was measured in degrees.

MATLAB was used to analyze the collected data. Mean values and their respective standard deviations were obtained for outcome measures of balance (center of mass, ankle, and hip sway), gait (normal and fast walk), cognition (Trail Making A and B), and psychosocial assessment (Fear of Falling and CES-D). P-values for the baseline characteristics between intervention and control groups were calculated using t-tests while those for the outcome variables were calculated using analysis of covariance (ANCOVA) to compare the effect of the intervention at follow-up with adjustment for baseline values.

For this study, participants were required to complete a capacity to consent in addition to an informed consent form to ensure that the patients diagnosed with MCI were able to understand the study procedures.

RESULTS:

From Banner Sun Health Research Institute, 68 patients diagnosed with MCI were identified. Of those patients, 37 met the inclusion criteria and 22 (59%) agreed to participate in the study. Of the 22 recruited participants, 10 were randomized to the control group and 12 were randomized to the intervention group. Both arms of the study had 1 participant lost to follow-up as a result of medical events outside of the study, resulting in the analysis of 9 control group participants and 11 intervention group participants (Figure 1).

At the end of the recruitment period, baseline characteristics were calculated to validate the randomization of the study. There were no significant differences between intervention and control groups on the baseline characteristics of age, gender, BMI, cognition, activities of daily living, depression, physical and mental health, fear of falling, number of comorbidities, number of prescriptions, self-reported pain, number of falls in the past year, use of walking aid, living situation,

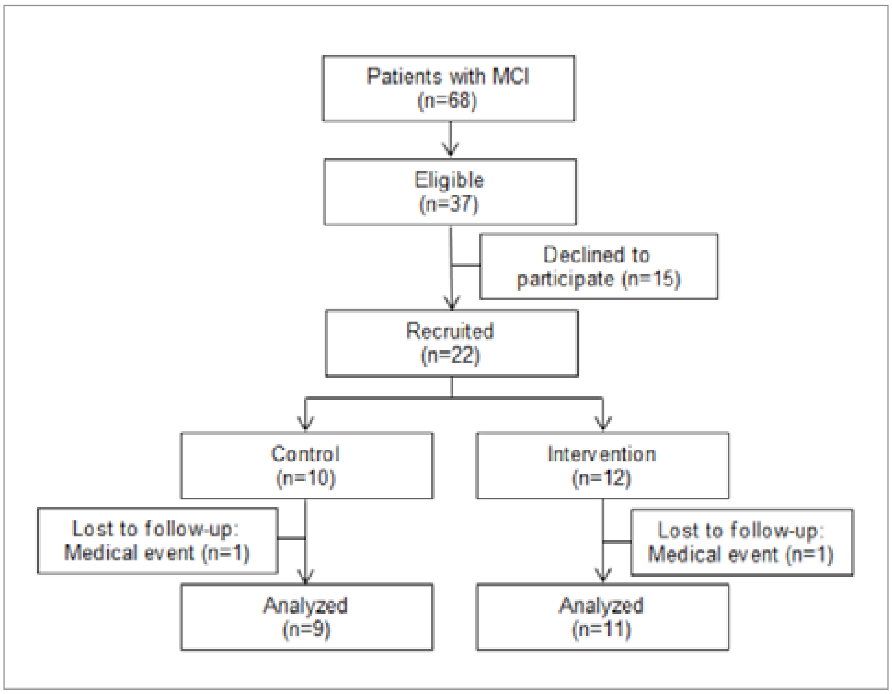

Figure 1. Recruitment flow chart

FULL-LENGTH

and mobility assessment (Table 1), suggesting that randomization was successful.

Results for the primary outcomes of interest, balance and gait, are shown in Figure 2. Balance measurements gave robust results, indicating statistically significant decreased center of mass sway (p=0.041), ankle sway (p=0.015), and hip sway (p=0.031) in the intervention group as compared to the control group. Trends remained consistent, with decreased sway in the intervention group and increased sway in the control group for anatomical locals of the waist, ankle, and hip.

Data are mean ± standard deviation or number (%); P- values are given for difference between the intervention and control group; SF, Short Form Health Survey; Canter for Epidemiological Studies Depression Scale (CES-D).

Results for gait were more variable with no significant differences for normal walk (p=0.349), or fast walk (p=0.220) tasks. Normal and fast walk data showed differences in trends between normal walking and fast walking speeds. With the normal walk task, there was an increase in walking speed (meters/second) in both the intervention and control group while the fast walk task indicated trends of increased walking speed in intervention group participants and decreased walking speed for the control group.

Cognitive and psychosocial assessments were also relatively variable (Figure 3). Cognitive assessments showed no difference between intervention and control group participants in either Trail Making A (p=0.689) or the more cognitively challenging Trail Making B (p=0.738) tasks. Trends for this set of assessments showed a slight decrease in time to complete the task for the intervention group and slight increase for the control group in Trail Making A, but slight increases in both intervention and control groups in the Trail Making B task.

In contrast, the results for the given psychosocial assessments appeared to follow hypothesized trends in improving cognition and psychosocial measurements more closely. There was a decrease in fear of falling as measured by the Short Falls Efficacy Scale in the intervention group when compared to the control group (p=0.015),with a decrease in the fear of falling score in the intervention group and an increase in score in the control group at follow-up when compared to baseline.

The CES-D scale showed trends of decreased depressive signs in intervention group and increased depressive signs in those in the control group, but these difference were not significant (p=0.156).

DISCUSSION:

This pilot study of virtual reality based balance training demonstrates effectiveness in improving balance in patients diagnosed with MCI. Results for balance were fairly robust, with similar trends for sway measurements from the various anatomical sites of the wearable sensors. Overall, the results for improving balance were promising in patients with MCI. Further testing should be done to validate the results for gait, especially for the fast walk task. Secondary outcomes of interested showed more variable results, with no significant changes in cognitive measures as assessed by both Trail Making A and B tasks. However, psychosocial measures indicated potential targets for intervention, with decreases in fear of falling in the intervention group with suggested improvement in depressive signs.

Baseline characteristics of study participants	Intervention (n = 12)	Control (n = 10)	P-value
Age, years	77.8 ± 6.9	79.0 ± 10.4	.756
Women, number	7 (58.3)	5 (50.0)	.696
BMI, kg/m^2	27.3 ± 3.4	24.8 ± 5.0	.182
Montreal Cognitive Assessment, score	23.3 ± 3.1	22.4 ± 3.0	.484
Education, years	14.2 ± 2.3	15.9 ± 2.7	.134
Barthel Activities of Daily Living, score	99.6 ± 1.4	98.0 ± 3.5	.206
CES-D scale, score	3.6 ± 3.2	3.0 ± 2.8	.638
SF-12, Physical Component, score	48.8 ± 8.3	45.7 ± 13.8	.510
SF-12, Mental Component, score	57.6 ± 5.0	58.1 ± 3.8	.793
Short Fall Efficacy Scale, score	4.7 ± 4.5	8.7 ± 1.8	.986
Diagnoses, number	2.5 ± 1.6	3.5 ± 2.1	.218
Prescriptions, number	4.0 ± 2.0	6.3 ± 3.9	.090
Visual Analogue Pain Scale (0-10), score	1.3 ± 1.9	0.8 ± 1.1	.432
History of falls in the last year, number of participants	6 (50)	3 (30)	.342
Walking aid user, number	1 (8.3)	1 (10)	.892
Community dwelling, number	12 (100)	10 (100)	1.000
Timed up and go, sec	10.2 ± 3.9	9.7 ± 1.7	.714

Data are mean ± standard deviation or number (%); P- values are given for difference between the intervention and control group; SF, Short Form Health Survey; Canter for Epidemiological Studies Depression Scale (CES-D).

Table 1. Baseline characteristics

As MCI has been demonstrated to reduce physical functioning and increased balance issues,[15] these results further add to the literature on the use of computer-based training in improving physical functioning in older adults with cognitive impairments.[17] While no differences were demonstrated in performance of cognitive tasks after the intervention, decreased Fear of Falling scores and suggested improvement in depressive signs may hold potential in dealing with the neuropsychiatric aspects of MCI[21] and should be further explored.

Participants in the intervention group received on average 4 weeks of training with appointments twice a week, personal as well as study scheduling conflicts introduced some variability into the study. Although all participants attended 8 training sessions with baseline and follow-up measurements, the spread of these training sessions remained relatively flexible to accommodate the participants' schedules. Currently there is insufficient evidence on the optimal duration of exercise programs used to reduce fall risk,[22] and the length of intervention may play a role in these outcomes. Since virtual reality technology is still in the process of being developed and made available to consumers, more research needs to be done to optimize the parameters of the training to produce the best results most effectively.

Problems encountered during balance training sessions were minor and included some difficulty in understanding the directions of the exercises in some patients and remembering these directions during or in following ses-

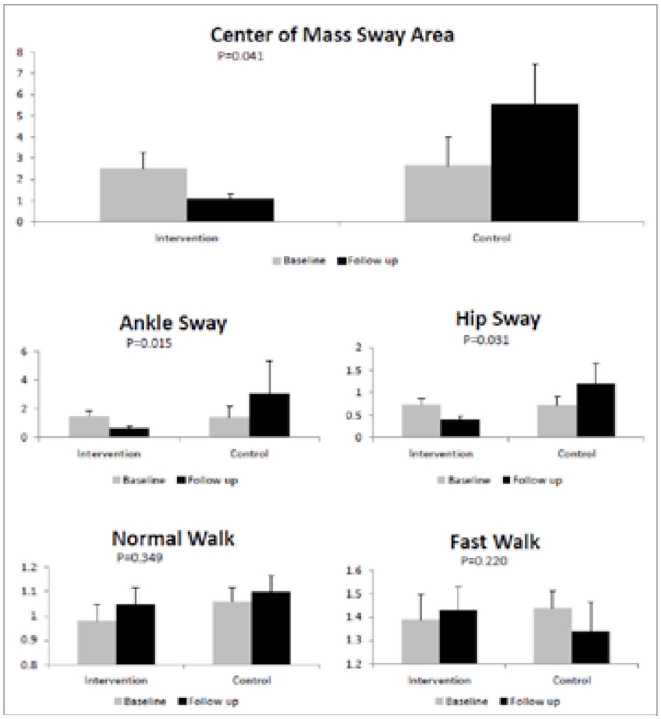

Figure 2. Primary outcomes: balance & gait measurements

sions, which often occurred in same participants, suggesting a range of cognitive functionality within the given patient population. Additionally, there were some technical issues with the wireless system. If participants were scheduled during the same time, the sensors would interfere with each other if the technology was being used within close proximity. Such technical error could be overcome by moving one of the participants to a different building and future difficulties can be avoided by renaming individual sensor systems so that they are not confused when registered within the same network.

A major limitation of this study is its small sample size (9 control and 11 intervention group participants). As a result, it is important to continue the study to increase the sample size in order to eliminate the large effects of individual variability in the data. Individual participants demonstrated a fairly wide range of abilities in cognition and physical activity. Given a larger sample size, future studies may be able to elucidate the efficacy of such intervention in individuals at different ends of the spectrum by stratifying by both cognitive and physical

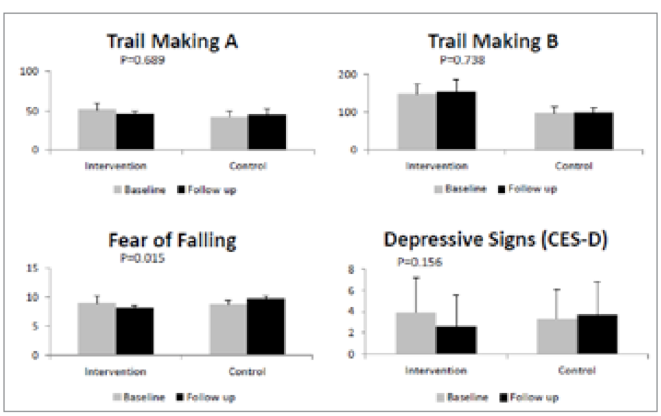

Figure 3. Secondary outcomes: cognition & psychosocial measurements

ability. This would give more information about the efficacy of the intervention in individuals at different baseline functions of cognition and physical activity.

These data continue to contribute to the growing body of research on the feasibility and effectiveness of virtual reality based exercise programs in various populations. Particularly in elderly individuals diagnosed with MCI, such interventions have the ability to improve balance and to lessen an individual's fear of falling. Thus, this technology has the capacity to mitigate the fall risk resulting from a decline in cognitive processes and serves as a means by which individuals can deal with their fear of falling. In the context of public health, the project contributes to the core functions of assessment, by monitoring health status as a function of balance, gait, cognition, and psychosocial indicators; policy development, through informing, empowering, and educating individuals of increased fall risk as a result of cognitive impairments; and assurance, via the evaluation of a growing paradigm in exercises based in virtual reality.

CONCLUSION:

This study has demonstrated effectiveness for the suggested virtual reality based balance training program in improving balance and fear of falling. Primary outcomes of interests for the given intervention included balance and gait, with secondary outcomes of interest in cognition and psychosocial assessments. While statistically significant improvement was demonstrated in all 3 balance measures as well as fear of falling in the Short Falls Efficacy Scale, trends in increasing walk speed during fast walk and decreased in depressive signs as captured by the CES-D questionnaire suggests potential in addressing these outcomes. Future studies with larger sample sizes as well as increased intervention time should be performed to further validate these results as well as to optimize the parameters in designing an intervention to mitigate the outcomes associated with MCI as well as to potentially prevent the progression of MCI to the more severe diagnosis of dementia. Virtual reality based exercise programs are becoming increasingly popular with the advancement of technology and has great potential as a tool to promote physical activity in elderly populations. For those with MCI, virtual reality based balance training has been shown here as one solution for dealing with the physical aspects of impairments in cognition, offering insight into the potential for this technology in promoting healthy aging in the most rapidly growing cohort in the population worldwide.

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