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Improvements in Gait Speed and Weight Shift of Persons With Traumatic Brain Injury and Vestibular Dysfunction Using a Virtual Reality Computer-Assisted Rehabilitation Environment

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ABSTRACT Many people sustaining a traumatic brain injury experience vestibular pathology requiring physical therapy for treatment. This study measured improvements in gait speed and weight shift for subjects receiving vestibular physical therapy using a Computer-Assisted Rehabilitation Environment (CAREN). A 6-session CAREN, 6-session traditional vestibular therapy group was compared with a 12-session CAREN only (0 traditional sessions) therapy group. These two groups were compared to each other and with data from healthy controls performing similar tasks on the CAREN. Those participating in 12 CAREN sessions had greater improvements in gait speed ($p = 0.014$) and weight shift scores ($p < 0.001$) and demonstrated similar values achieved by a healthy control population.

INTRODUCTION

Since 2000, the Defense Veterans Brain Injury Center has reported over 300,000 cases of traumatic brain injury (TBI) in military service members, which includes injuries occurring in both deployed and nondeployed settings.[1] TBI, which often results from blast exposure, has been described as the "signature injury" of the wars in Iraq and Afghanistan.[2,3] Despite recent advances in the battlefield diagnosis of TBI, mild TBI (mTBI) is difficult to diagnose in the war zone, and the condition likely is under-reported.[3] A common problem among service members who have sustained a TBI includes balance and vestibular disorders that require vestibular physical therapy (VPT) for treatment.[4–6] Many different types of exercise procedures are used to target[6,7] and test[8] the vestibulo-ocular reflex, the cervico-ocular reflex, and depth perception, including balance, gait, and aerobic exercises. Following concussion, vestibular rehabilitation may lead to improvements in balance and gait.[9] Vestibular rehabilitation that includes customized exercise programs for outcomes such as gaze stabilization, dynamic postural stability, and dynamic visual acuity, provides the best results for improving patient symptoms, with most patients responding to the treatment within 8 weeks.[6]

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Recently, more advanced technology at military treatment facilities has been used for rehabilitation of the wounded warrior, including the use of virtual reality systems for VPT.[10] Virtual reality systems such as the CAREN (Motek Medical BV, Amsterdam, the Netherlands) provide platforms that can challenge subjects both physically and cognitively in realistic yet controlled environments that are interactive and engaging. The CAREN at the Naval Health Research Center (NHRC) consists of a motion platform (Moog, East Aurora, New York) that can move in any of its 6 degrees-of-freedom and is surrounded by a 10-ft tall, 180° screen, which immerses the subject within the projected virtual environment. The virtual scene projected on the screen can be programmed to move in synchronization with the treadmill and platform, providing visual flow for dynamic tasks, or it can be held still for static tasks. Built into the platform is an instrumented dual-belt treadmill (Forcelink BV, Culemborg, the Netherlands) that can measure the ground reaction forces of the subject as they move. An incorporated motion capture system (Motion Analysis Corporation, Santa Rosa, California) allows the subjects to interact with their environment as well as allows objective movement data to be recorded during therapy sessions. The laboratory environment of the CAREN allows for controlled, repeatable scenarios to be displayed during assessments.[11] The components of the CAREN are highly customizable, allowing the difficulty of tasks, complexity of the therapy, and realism of the scene to be tailored to each patient. Many settings can be changed in real time to respond to the requirements needed for therapy of a particular subject at that particular time and day.

The purpose of this study was to measure gait speed and weight-shifting activities during various tasks in subjects receiving VPT using a CAREN system. Differences due to the number and type of treatment sessions were measured and speeds and scores from noninjured, healthy controls performing similar tasks within the CAREN were compared since this has not previously been reported.

METHODS

Patient Population

Service members who were referred to the Vestibular Therapy Clinic at the Naval Medical Center San Diego (NMCSD) were recruited for this study. Those who participated fell between the ages of 20 and 42. Patients presented with vestibular disorders related to an mTBI occurring within the past year (mean ± SD = 185 ± 85 days). Brain injury was previously diagnosed by attending physicians from one of the U.S. service branches. Those who were unable to tolerate a 6-week exercise program or had known severe limits to mobility (i.e., unable to walk without the assistance of a walker, cane, prosthesis, or orthosis) were excluded from the study. Subjects participated in a 6-week, 12-session therapy program under a qualified vestibular physical therapist. Sessions lasted between 20 and 30 minutes. Each subject was randomly assigned to one of two groups. Group 1 performed half (6) of the therapy sessions on the CAREN at the NHRC and the other half (6) using traditional vestibular therapy techniques[7] at NMCSD, with visits at each of the sites occurring once weekly for the 6 weeks. Group 2 performed all 12 therapy sessions on the CAREN at NHRC, twice weekly over the 6-week period. Volunteers gave written informed consent in accordance with the Institutional Review Board at NHRC.

Intervention

While participating in CAREN therapy, subjects were challenged physically and cognitively with several different virtual scenarios that required them to maintain their balance while standing on the platform or walking on the treadmill. Cognitive performance tasks were used (e.g., Stroop test, math equations, hand target acquisition, target identification, and shooting accuracy) in the different applications. Physical performance tasks included maintaining balance as the platform gyrated, tilted, or shifted laterally (Fig. 1), walking up and down hills while swatting at moving objects, walking over

FIGURE 1. Photo of a vestibular subject walking on the CAREN on an endless pastoral path. In this application, the subject sets his own walking speed by pressing up and down buttons on a wireless hand controller. © Naval Health Research Center. Reprinted by permission.

FIGURE 2. Photo of a vestibular subject steering a boat through a slalom course on the CAREN. Wave height, platform movement, and maximum boat speed can be set by the CAREN operator. In this application, the subject must maneuver through the course as fast and with as few errors (e.g., hitting buoys) as possible. © Naval Health Research Center. Reprinted by permission.

uneven terrain while holding and firing a mock weapon, or weight shifting to steer a boat through an obstacle course (Fig. 2). As performance improved, platform motion, difficulty of the tasks, or time on the tasks increased. A more detailed explanation of the different applications used has been previously presented.[12]

During these sessions, several measurements of performance on the CAREN were recorded at each visit. One measurement was the self-selected walking speed while walking on the CAREN treadmill. During the first task of walking on a virtual pastoral road, subjects used a wireless hand controller to set their comfortable walking speed. Their average treadmill speed during the task was recorded as their self-selected walking speed for that session. Subjects walked for approximately 3 minutes for this portion of the task. No platform motion occurred during this time.

Score on a boat-steering task was also used as a measure of performance. Subjects were asked to control a boat through a course of buoys as quickly as they could while trying not to hit any objects (buoys and islands) with the boat. Steering was controlled by the subject using motion capture markers placed on their shoulders. The platform moved with the boat as it moved over the waves and with the steering of the subject. Because the boat task was a weight-shifting task that required driving a simulated boat using body movement, subjects' performance was based on task planning and balance ability and not necessarily experience on a ship or boat. The score, a measure of both speed and accuracy, was calculated using an algorithm that incorporated time to complete the course, height and speed of platform motion, maximum allowable boat speed, and number and type of errors (i.e., hitting objects with the boat or not successfully passing a target buoy) made by the subject. At the first visit, patients started with relatively low settings for platform motion, maximum allowable boat speed, and wave height, to get comfortable with the application. Subjects, using their body to control boat speed and direction by shifting their weight, increased their scores by reducing the time to complete the course and number of errors made. At successive sessions, subjects vocalized their comfort with the previous and current settings before the therapist increased the setting difficulty through modifications in wave height or maximum boat speed, but settings were always set to challenge the patient. Changes to these settings were made subjectively by the therapist and were accounted for in the boat scoring system.

To compare performance over visits between Groups 1 and 2, differences in measurements were analyzed for the first 6 visits of each group (Visits 1 through 6). Differences over comparable weeks of therapy were also evaluated, as Group 2 had more CAREN visits, and Group 1 had more visits to NMCSD's vestibular therapy clinic. Performance measurements at the end of Week 2 (CAREN Visit 2 for Group 1, Visit 4 for Group 2), Week 4 (CAREN Visit 4 for Group 1, Visit 8 for Group 2), and Week 6 (CAREN Visit 6 for Group 1 and Visit 12 for Group 2) were compared between Group 1 and Group 2.

Control Group

Similar measurements to those obtained from the vestibular groups were previously obtained from noninjured populations. These data were used for comparison with the patient population described above. For the self-selected walking measurements, data were obtained from a convenience sample of 20 active-duty male military personnel (mean ± SD age: 33.6 ± 6.6 years, height: 175.3 ± 7.1 cm, and weight: 80.9 ± 12.6 kg) with no reported prior history of TBI or concussion, musculoskeletal injuries, or surgeries affecting their gait. All 20 subjects completed the study and no subjects were excluded from the analyses. These subjects were asked to choose a comfortable walking speed using a wireless hand controller while walking down a virtual hallway in the CAREN. Average treadmill speed was recorded over approximately 3 minutes as subjects walked on the treadmill. Data were obtained from only one time point for these subjects since there was only one visit for this study.

Scores from the boat-steering task were also measured in a separate control population. Data were collected from a convenience sample of 7 healthy male subjects (mean ± SD age: 28.7 ± 4.2 years, height: 176.6 ± 5.2 cm, and weight: 79.3 ± 12.2 kg) with no reported prior history of TBI or concussion, vestibular or musculoskeletal issues or tendency toward motion sickness. All 7 subjects completed the study and no subjects were excluded from the analyses. These subjects performed the boat-steering task twice weekly for 6 weeks, similar to vestibular therapy subjects in Group 2, except that the system settings were set at the highest level of difficulty throughout the 12 visits. Thus, though the same scoring system as that for the vestibular therapy patients was used; changes in score were based on average speed, time to completion, and number of errors made during the session. Data from the same time points (Visits 1 through 6, and visits at end of Week 2, Week 4, and Week 6) were compared with the boat scores of the two vestibular groups.

Volunteers gave written informed consent in accordance with the NHRC Institutional Review Board.

Statistical Analyses

A mixed between-within subjects analysis of variance was conducted to explore the impact of group type and time on self-selected walking speed and boat-steering scores. Post hoc analyses were performed to examine the differences between groups at the different time points. Standard statistical software (IBM SPSS, Armonk, New York) was used. Significance was defined as $p \leq 0.05$.

RESULTS

A total of 26 vestibular subjects were consented for this study. Two subjects completed the intervention but were not included in the analyses because one subject needed walking aids during therapy and the second subject was unable to tolerate completing the boat application in any visit. Data from 12 vestibular subjects (mean age: 31.9 ± 5.6 years; height: 171.2 ± 8.8 cm; and weight 87.0 ± 12.3 kg) who were assigned to Group 1 were included in the analyses. Twelve subjects (mean ± SD age: 27.5 ± 4.9 years; height: 181.0 ± 8.74 cm; and weight: 84.3 ± 15.4 kg) assigned to Group 2 completed the 12 sessions of therapy and were also analyzed for this portion of the study.

Gait Speed

Self-selected walking speeds of all the vestibular subjects initially ranged from 0.29 to 0.86 m/s at their initial visit (Visit 1). By the end of the therapy (Week 6), speeds ranged from 0.60 to 1.50 m/s. Self-selected walking speeds for the Control group ($N = 20$) ranged from 0.85 to 1.48 m/s.

Gait Speed Across the First 6 Visits

A mixed between-within subjects analysis of variance was performed to analyze the differences between comparable visits (Visits 1 through 6) for the different groups. There was not a statistically significant main effect for group type $F(1,16) = 2.78$, $p = 0.115$, $\eta_p^2 = 0.148$. Post hoc analyses (Table I) showed that there were no statistical significances between Groups 1 and 2 at comparable visits for all Visits 1 through 6 ($p > 0.05$). However, there was a significant effect for time point $F(5,80) = 20.22$, $p < 0.001$, $\eta_p^2 = 0.558$, with walking speeds increasing over time in both groups. *t*-Tests were performed to compare walking speeds between the Control group and vestibular groups. Group 1 walked significantly slower compared to the Control group at Visit 1 ($t(28) = 7.59$, $p < 0.001$, $d = 2.89$), Visit 2 ($t(30) = 3.24$, $p = 0.003$, $d = 1.11$), and Visit 3 ($t(30) = 3.43$, $p = 0.002$, $d = 1.19$), but not for Visit 4 ($t(29) = 1.83$, $p = 0.139$, $d = 0.631$), Visit 5 ($t(30) = 2.22$,

TABLE I. *t*-Tests Comparing Gait Speed and Boat Navigation Scores at Comparable Visits (1–6) and Weeks (2, 4, and 6) for the Three Groups (Group 1, Group 2, and Control Group)

Group Pair	Visit Number	*p* Value Gait Speed	*p* Value Boat Score	Week Number	*p* Value Gait Speed	*p* Value Boat Score
Group 1 vs. Group 2	1	0.167	0.392	2	0.211	0.007*
	2	0.997	0.085	4	0.046*	0.009*
	3	0.245	0.050*	6	0.023*	0.041*
	4	0.742	0.486			
	5	0.252	0.505			
	6	0.563	0.713			
Group 1 vs. Control	1	<0.001*	0.012*	2	0.003*	<0.001*
	2	0.003*	<0.001*	4	0.139	<0.001*
	3	0.002*	<0.001*	6	0.177	<0.001*
	4	0.139	<0.001*			
	5	0.070	<0.001*			
	6	0.242	0.003*			
Group 2 vs. Control	1	<0.001*	0.060	2	0.199	<0.001*
	2	0.001*	<0.001*	4	0.230	0.001*
	3	0.078	0.002*	6	0.050*	0.005*
	4	0.199	<0.001*			
	5	0.362	<0.001*			
	6	0.556	<0.001*			

*p Values < 0.05 were considered significant.

$p = 0.070$, $d = 0.754$), or Visit 6 ($t(29) = 1.38$, $p = 0.242$, $d = 0.485$). Group 2's walking speeds were significantly slower than the Control group at Visit 1 ($t(28) = 7.59$, $p < 0.001$, $d = 3.19$) and Visit 2 ($t(28) = 7.59$, $p < 0.001$, $d = 1.35$). But the next 4 visits showed Group 2's walking speed was within 0.14 m/s to the Control group's speed, and was not significantly different at Visit 3 ($t(30) = 1.82$, $p = 0.078$, $d = 0.634$), Visit 4 ($t(30) = 1.34$, $p = 0.199$, $d = 0.512$), Visit 5 ($t(30) = 0.925$, $p = 0.362$, $d = 0.331$), or Visit 6 ($t(30) = 0.595$, $p = 0.556$, $d = 0.206$).

The predicted interaction between time point and group for walking speed was not statistically significant, $F(5,80) = 1.02$, $p = 0.414$, $\eta_p^2 = 0.060$).

Gait Speed Across the 6 Weeks of Therapy

A mixed between-within subjects analysis of variance was used to compare the groups over weeks. Mean walking speed increased for both Groups 1 and 2 over the 6 weeks (Fig. 3). Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(2) = 6.17$, $p = 0.046$), therefore degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ($\varepsilon = 0.767$). There was a significant effect for time point, $F(2,36) = 23.05$, $p < 0.001$, $\eta_p^2 = 0.562$. There was also a statistically significant main effect for group type, $F(1,18) = 7.36$, $p = 0.014$, $\eta_p^2 = 0.290$. Post hoc tests showed that, although not significantly different at Week 2 ($t(22) = 1.29$, $p = 0.211$, $d = 0.526$), Group 2 walked significantly

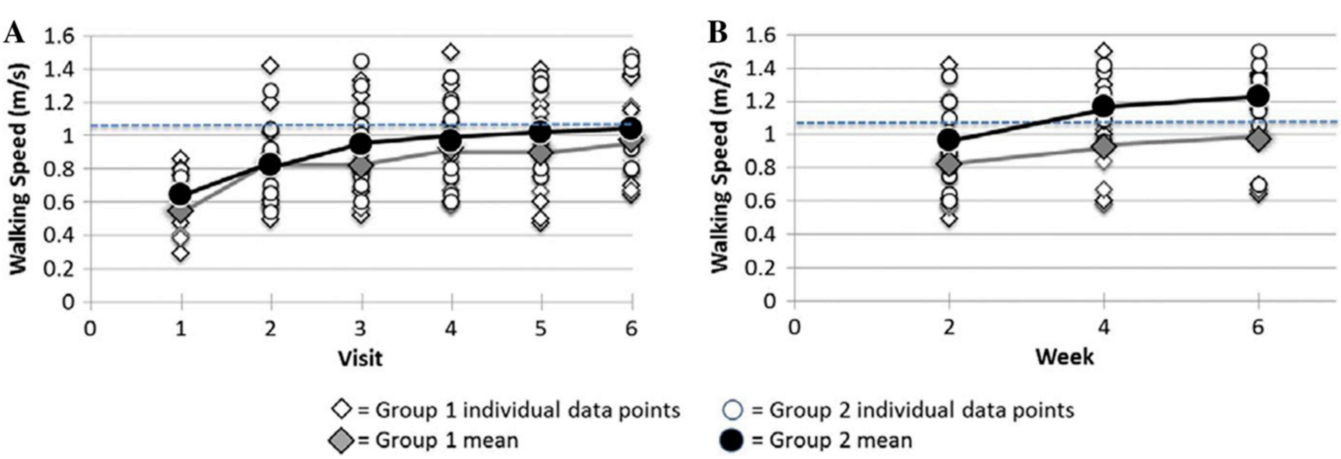

FIGURE 3. Self-selected walking speeds for both vestibular groups at (A) the first 6 visits on the CAREN and (B) at the end of Weeks 2, 4, and 6 of the 6-week therapy intervention. Group 1 data are plotted with diamond markers and Group 2 data are plotted with circle markers. Individual data for each subject are the white markers, whereas mean values for each group for each time point are plotted as the larger filled markers (Group 1 mean = filled diamond markers; Group 2 mean = filled circle markers). The mean self-selected walking speed for the Control group was 1.08 m/s and is plotted as the dotted line on the graph.

faster at Week 4 ($t(18) = 2.14$, $p = 0.046$, $d = 0.991$) and Week 6 ($t(20) = 2.46$, $p = 0.023$, $d = 1.048$) compared with subjects in Group 1.

Independent samples *t*-tests were run between the Control group and vestibular groups. Group 1 showed significantly lower speeds at Week 2 ($t(30) = 3.24$, $p = 0.003$, $d = 1.11$) compared with the Control group, but was not significantly different by Week 4 ($t(29) = 1.83$, $p = 0.139$, $d = 0.631$) or Week 6 ($t(29) = 1.38$, $p = 0.177$, $d = 0.485$). Group 2's walking speeds were not significantly different from that of the Control group at either Week 2 ($t(30) = 1.34$, $p = 0.199$, $d = 0.513$) or Week 4 ($t(27) = 1.23$, $p = 0.230$, $d = 0.499$). By Week 6, Group 2 walked significantly faster ($t(29) = 2.05$, $p = 0.050$, $d = 0.744$) than the Control group.

The interaction effect between time point and group for walking speed was not statistically significant, $F(2,36) = 1.23$, $p = 0.147$, $\eta_p^2 = 0.064$.

Boat Navigation Scores

Similarly to gait speed, mean scores when performing the boat application also increased over visits (Fig. 4). Boat scores initially ranged from 869 to 1,182 points (mean ± SD: 1,059 ± 83 points) at their initial visit (Visit 1) for all vestibular subjects. By the end of the therapy (Week 6), scores ranged from 914 to 1,440 points (mean ± SD: 1,233 ± 204 points). For some subjects, no platform motion or waves were given at the initial visit, whereas others were comfortable with 100% platform movement and about 30% wave movement. By the end of therapy, all subjects had at least 10% platform motion and 20% wave movement, and a maximum of 100% platform and wave movement. These settings were accounted for in the boat scoring.

Boat scores for the Control group ($N = 7$) ranged from 1,024 to 1,333 points (mean ± SD: 1,206 ± 123 points) at their initial visit and 1,402 to 1,440 points (mean ± SD: 1430 ± 15 points) by their last visit (Visit 12).

Boat Navigation Scores Across the First 6 Visits

Statistical differences between the first 6 visits (Visits 1 through 6) for the different groups were analyzed using a mixed between-within subjects analysis of variance. There was a statistically significant main effect for group type $F(2,17) = 25.04$, $p < 0.001$, $\eta_p^2 = 0.747$ and a significant effect for time point $F(5,85) = 28.61$, $p < 0.001$, $\eta_p^2 < 0.005$. Post hoc analyses showed that there were no statistical significances between Groups 1 and 2 at comparable visits for Visits 1, 2, 4, 5, or 6 ($p > 0.05$), but significant differences were observed for Visit 3 ($t(17) = 2.17$, $p = 0.050$, $d = 0.940$), with mean scores of Group 2 being higher than Group 1. When comparing the scores between the Control group and vestibular groups, the scores of Group 1 were significantly slower than the Control group for all Visits 1 through 6 ($p > 0.05$). Group 2's boat scores were not significantly different at Visit 1 ($t(12) = 2.07$, $p = 0.060$, $d = 1.11$), but were significantly lower compared to the Control group for the next 5 visits ($p < 0.05$).

The predicted interaction between time point and group for walking speed was not statistically significant, $F(10,85) = 0.639$, $p = 0.776$, $\eta_p^2 = 0.070$.

Boat Navigation Scores Across the 6 Weeks of Therapy

A mixed between-within subjects analysis of variance was also used to compare the groups over weeks, showing that scores increased for all groups (Groups 1 and 2 and the Control group) over the 6 weeks (Fig. 4). There was a statistically significant main effect for group type, $F(1,23) = 26.75$, $p < 0.001$, $\eta_p^2 = 0.699$, and time point, $F(2,46) = 46.73$, $p < 0.001$, $\eta_p^2 = 0.670$. Post hoc tests showed that the scores for Group 2 were significantly higher compared to Group 1

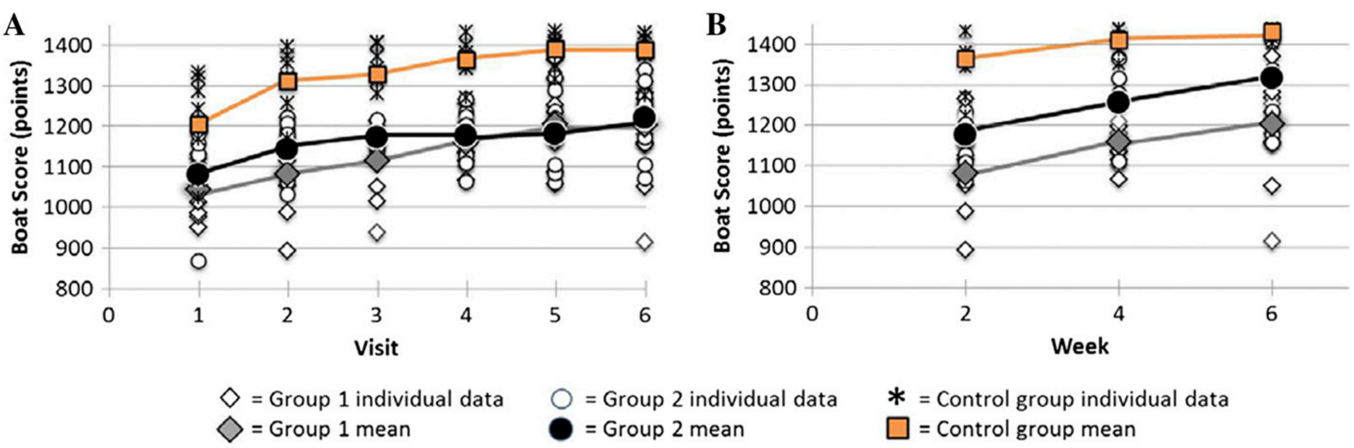

FIGURE 4. Boat scores for both vestibular groups and the Control group at (A) the first 6 visits on the CAREN and (B) at the end of Weeks 2, 4, and 6 of the 6-week therapy intervention. Group 1 data are plotted with diamond markers, Group 2 data are plotted with circle markers, and Group 3 data are plotted with asterisk/star markers or square markers (for mean data). Individual data for each subject are the unfilled markers while mean values for each group for each time point are plotted as the larger filled markers (Group 1 mean = filled diamond markers; Group 2 mean = filled circle markers, Control group mean = filled square markers). Control group mean scores remained higher than vestibular groups at all time points. Group 2 mean data remained at or higher than Group 1.

for all weeks (Week 2 [$t(19) = 3.00$, $p = 0.007$, $d = 0$], Week 4 [$t(19) = 2.93$, $p = 0.009$, $d = 0.109$), and Week 6 [$t(21) = 2.18$, $p = 0.041$, $d = 0.917$]).

Compared with the Control group, Group 1 had significantly lower scores across all time points (Week 2: $t(15) = 7.85$, $p < 0.001$, $d = 3.42$; Week 4: $t(16) = 11.05$, $p = < 0.001$ $d = 2.18$; and Week 6: $t(17) = 4.31$, $p < 0.001$, $d = 1.50$). Group 2 also had significantly lower scores than the Control group at Week 2: $t(16) = 6.96$, $p < 0.001$, $d = 3.42$; Week 4: $t(15) = 4.11$, $p = 0.001$, $d = 2.17$; and Week 6: $t(15) = 2.79$, $p = 0.005$, $d = 1.51$.

The interaction effect between time point and group for walking speed was not statistically significant, $F(4,46) = 1.23$, $p = 0.063$, $\eta_p^2 = 0.173$.

DISCUSSION

Measurements of walking speed in the CAREN were slower than those previously reported for overground walking in the Control group, as well as the vestibular groups at the earlier time points (i.e., Visit 1).[13] This may be the result of an acclimatization period for subjects to adapt to walking on a moving platform and treadmill within a virtual environment. Though self-selected walking speeds were significantly different than the Control group at the initial visit (Visit 1) for both vestibular groups, walking speeds achieved by Group 2 were similar to the Control group by Week 2, whereas Group 1 did not achieve similar walking speeds until Week 4. By the end of the 12 therapy sessions, the vestibular group walking speeds were at or above the self-selected speeds presented by the Control group.

Performance on the boat-steering task was similar for both vestibular groups at the beginning of therapy. Although both vestibular groups' boat scores remained lower than that of the Control group throughout the therapy sessions, Group 2 progressed faster and scores were more similar to the Control group. Although not significantly different at the first visit (Visit 1), Group 2 had significantly higher scores than Group 1 by Week 2, and remained higher through the rest of the weeks of therapy. This may be because Group 2 had more sessions within the CAREN (i.e., 12 vs. 6), which allowed them more practice walking in the CAREN and on the boat-steering task. Another reason may be that the challenges presented in CAREN-based therapy allowed larger improvements in balance and task planning. Although the scoring system tried to reflect the changes in setting difficulty and speed and accuracy of the subject, the multiple dependent variables that were altered throughout the study may confound the results observed between sessions and groups. Future studies in which settings between sessions and groups remain consistent may help to reduce these confounds.

It would be useful to validate these changes with clinical measurements usually performed in traditional vestibular therapy clinics (e.g., dynamic posturography/sensory organization test, functional gait assessment), and current research is ongoing to correlate these clinical measures with those performed on the CAREN. Data are currently being collected from a third group who are performing all therapy sessions using traditional vestibular therapy techniques at NMCSD. Research comparing the results of current vestibular clinical tests from all three groups may help to determine what benefits the CAREN may offer over traditional therapy or what combination of therapies may best benefit the Wounded Warrior. Future studies should also test the performance of vestibular patients doing tasks on the CAREN (e.g., walking speed and boat scores) at specified time points of traditional therapy, but not using the CAREN for therapy. This would help to validate certain applications and measurements taken on the CAREN as quantifiable measures of improvement in vestibular function and coordination that could be used clinically. Using the baseline scores of healthy subjects and those using the CAREN for treatment as reported here will help to set outcome scores of patients using CAREN applications for assessment.

CONCLUSIONS

Measures such as walking speed and boat-steering performance scores improved after 6 weeks of VPT and may be related to improvements in balance and gait. Those subjects participating in 12 sessions on the CAREN had greater improvements in gait speed and challenges involving weight shifting on the CAREN, and demonstrated similar values achieved by a healthy control population. These findings suggest that the CAREN system may be an effective treatment modality for persons with vestibular dysfunction. Although setup and operation of the CAREN is relatively expensive, there are CAREN systems currently in use at four different military treatment facilities in the U.S. Many service members can be referred for treatment at one of these facilities if their health care providers believe they can benefit from the unique capabilities and challenges that the CAREN can offer in addition to or in place of traditional clinical therapies. Because of the ability to simulate more dynamic environments than those usually found in traditional VPT, and the ability to dual task with physical and cognitive challenges, use of the CAREN or similar technology is promising for use in therapy, particularly for those patients that need greater challenges than those traditionally used in the clinic.

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