

Vestibular Physical Therapy Intervention: Utilizing a Computer Assisted Rehabilitation Environment in lieu of Traditional Physical Therapy

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Abstract— Advanced technology such as virtual reality or immersive environments increases the complexities and challenges therapists can impose on their patients. In this study, four patients with mild traumatic brain injury utilized a Computer Assisted Rehabilitation Environment (CAREN) in place of traditional vestibular physical therapy. Patients visited the CAREN twice weekly for 6 weeks. Therapy sessions included a variety of applications that tasked the cognitive and physical capabilities of individual patients. After the 6 weeks, all patients showed improvement on balance, gait and visual measures. Virtual reality based therapy is an engaging and effective tool to treat patients with deficiencies related to a prior brain injury.

I. INTRODUCTION

Mild traumatic brain injury (mTBI) and associated vestibular dysfunction has been characterized and treated with conventional vestibular physical therapy. The lack of coordination between eye movement with head movement produces dizziness and unsteadiness [1-3]. In addition to the impact of head trauma on the basic vestibular reflex, there are demonstrated patterns of postural instability [4-7]. The majority of individuals suffering from blunt and blast trauma will have abnormalities in both the sensory-organization test and motor control posturography tests. In this test, as much as 70% of those with symptomatic balance complaints from mTBI will show abnormalities if untreated even if they present 18 months after their injury [5,6]. Currently, the Department of Defense utilizes virtual reality based therapy programs to rehabilitate wounded warriors [8]. Patients regularly interact with a variety of custom scenarios designed to challenge patients with musculoskeletal, vestibular and cognitive injuries. number text heads-the template will do that for you.

The purpose of this study is to examine physical therapy intervention with mild traumatic brain injury utilizing a virtual reality computer assisted environment. The CAREN involves using a moving platform with integrated treadmill and force plate that is referenced to a virtual scenario. The individual can be placed in a number of different balance

situations to challenge nascent balance function as well as test postural stability.

II. MATERIALS AND METHODS

A. Subjects

We recruited active duty service members (Age range: 22-27 years) referred to the Vestibular Therapy Clinic at the Naval Medical Center San Diego (NMCS D) Comprehensive Combat and Complex Casualty Care (C5) Center. Patients presented with vestibular disorders related to a recent mTBI (<1 year). Brain injury was previously diagnosed by active duty medical corps physicians. Volunteers gave written informed consent in accordance with the Institutional Review Boards at the Naval Health Research Center and NMCS D.

B. Balance Assessment Module

These tests were given to each subject prior to therapy, midway into therapy (3 weeks) and after completing the vestibular physical therapy program (6 weeks). These tests are those that are utilized at NMCS D to measure progress of therapy for patients receiving vestibular physical therapy.

1. Computerized dynamic posturography/ Sensory organization test (SOT): In this test, the patient is secured in a standing position on a platform in which the platform and surrounding structure move in response to patient motion (EquiTest, NeuroCom, Clackamas, OR). The test assesses postural stability, motor control and adaptation in a variety of different conditions.
2. Visual acuity and stable gaze test: In this set of tests, the patient peers into a visual tunnel (inVision, NeuroCom, Clackamas, OR) while seated and is asked to perform several tasks that involve visual and cognitive interaction. The tests include perception time, target acquisition time, target following speed, dynamic visual acuity test (DVAT), and gaze stabilization test (GST).
3. Functional Gait Assessment (FGA): A set of 10 gait tasks with a standardized grading system scored by a vestibular physical therapist trained in gait analysis.
4. Self-report questionnaires: Jacobson dizziness handicap index (DHI) and activities balance confidence scale (ABC).

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C. Computer Assisted Rehabilitation Environment



Figure 1: Computer Assisted Rehabilitation Environment (CAREN). A subject walks on the integrated treadmill while facing the synchronized projection screen. In the event of a stumble or fall, the subject is harnessed and tethered to a safety system.

The utilization of virtual environments as a rehabilitation tool has gained recent support at military medical treatment facilities. The Computer Assisted Rehabilitation Environment (CAREN, Motek Medical Inc, The Netherlands) is a unique device that provides a reactive environment for the patient (Fig. 1). Working in real-time, the environment tasks the patient with visual, auditory, tactile and vestibular sensory inputs. This enables researchers to analyze balance, posture, learning and locomotion behaviors.

The CAREN Extended model, utilized for this study, integrates a dual-belt instrumented treadmill (Forcelink Inc, The Netherlands) into a 10-foot diameter hydraulically actuated platform (Moog Inc, East Aurora, NY) programmed to move in six degrees of freedom (pitch, yaw, and roll by 35° and translation in x, y, and z axes). The platform is surrounded by a 180° nine foot tall projection screen. Three image generators controlled by the CAREN D-flow software synchronize the projected virtual scene with the movement of the platform and treadmill. A 12-camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA) allows the user to interact with each environment on the screen.

D. Therapy

The traditional vestibular physical therapy rehabilitation strategy employs specific exercises designed to reinstate spatial orientation and decrease vertigo. Specifically the vestibular physical therapy exercise programs included vestibulo ocular reflex (VOR) exercises, cervico ocular reflex (COR) exercises, depth perception training, somatosensory exercises, dynamic gait tasks, ball skills, positional exercises, aerobic exercises, proprioceptive neuromuscular facilitation exercises (PNF), and plyometrics. Patients are monitored by the vestibular physical therapist twice weekly until standards are met for

advancement or return to duty, or medical board is processed for military separation or retirement.

For this study, volunteers either participated in 12 sessions of traditional vestibular physical therapy at NMCSO or participated in a 12 session CAREN vestibular physical therapy program at the Naval Health Research Center (NHRC) Warfighter Performance Laboratory. This paper reports findings from an initial group of 4 subjects participating in CAREN therapy. The CAREN rehabilitation strategy employed four interactive applications which were either created wholly at NHRC or were versions of an application originally provided by Motek Medical that were customized at NHRC to provide engaging and challenging applications for this patient group. These applications are designed to integrate visual and tactile inputs for processing by the patient. Similar to traditional therapy, patients are monitored by the therapist and CAREN operating staff twice weekly. The difficulty of each application is incrementally increased to challenge the patient as they adapt. The patients used the following four applications each having different objectives (Fig. 2 shows a screen shot from each application):

1. Endless Road: (self-controlled walking speed) with arrow optotype, math equations, and stroop test;
2. Forest Road: (set preferred walking speed) with randomized hand target acquisition;
3. Mountain Terrain: (set preferred walking speed) rifle carriage, target identification, shooting accuracy;
4. Boat Slalom: (patient controlled movement) Standing weight shift boat course.

Patients began daily sessions with the Endless Road application. This program allowed patients to adjust the treadmill speed via wireless hand controller. Once their preferred walking speed was established, they began scanning the passing scenery for a set of cognitive tasks (Fig. 2a). These tasks included arrow optotype, simple addition of two numbers, and stroop test. Vestibular load was increased by adding platform gyrations, lateral shifts or lateral tilts of increasing magnitude during walking. This warmup challenged the vestibular system while being distracted cognitively.

After a rest, patients participated in the Forest Road walking application. The treadmill speed is set by the CAREN operator based on the patient's preferred walking speed in the Endless Road application, their current comfort level and previous performance. In this application, the motion platform (which can be increased as subject ability improves) moves in sync to the terrain changes in the forest scene (incline, decline, lateral shifts). Using the motion capture system, retroreflective markers placed on each hand allow the patient to virtually swat at flying objects that appear along the path. A hit is registered if they make contact (Fig. 2b) with the object. The system records total walking time and targets hit. This application works on

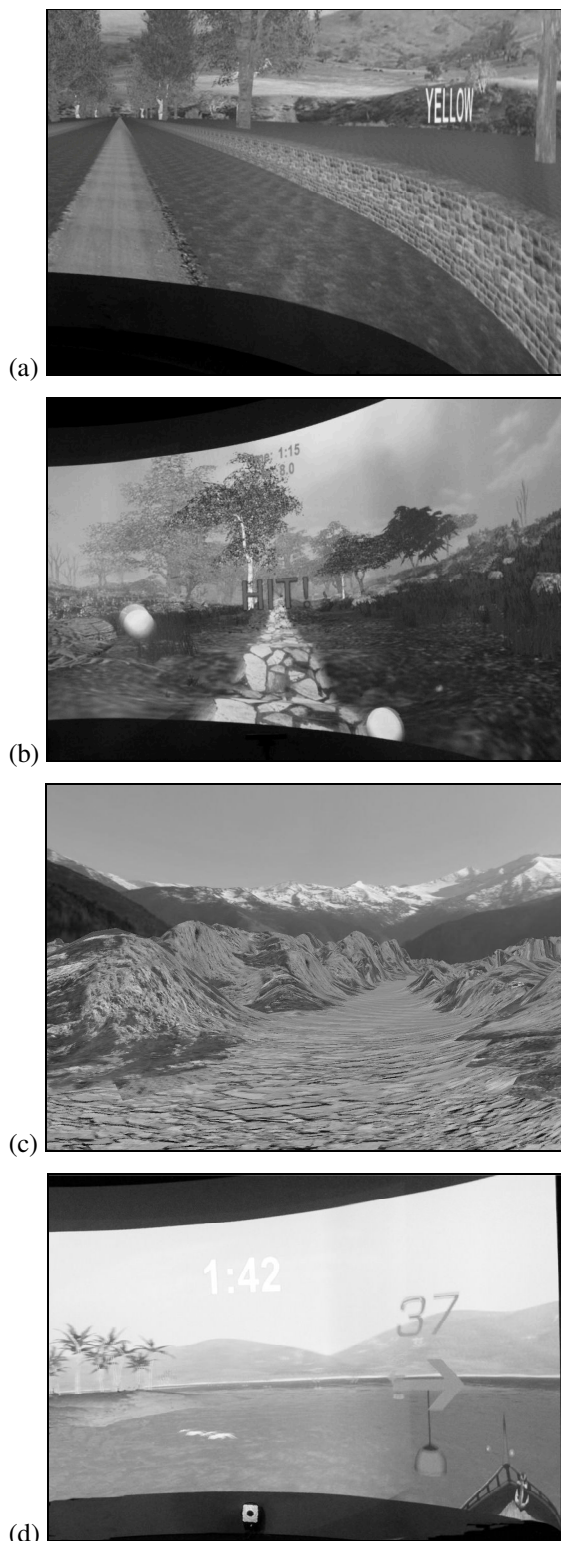


Figure 2. Grayscale screen shots of each application: a) Endless Road, with a strop task; b) Forest Road, with interactive markers hitting target; c) Mountain Terrain; d) Boat Slalom, at buoy number 37.

coordination and challenges the subject to reach beyond his comfortable limits.

Patients then participated in a final walking application. The Mountain Terrain (Fig. 2c) application is based on

current operational conditions in Afghanistan. Patients are given a realistically weighted rifle (US Marine Corps M4 type automatic electric gun) with wireless control to the CAREN software. The treadmill speed is set by the CAREN operator based on the patient's preferred walking speed in previous applications, their current comfort level and previous therapy session performance. In this application, the motion platform moves in sync to the terrain changes (incline, decline, lateral leans). At random intervals, targets appear statically (enemy, civilian, explosive devices) or dynamically (grenades) in the scene. Patients identify the target and shoot with the mock rifle. Aiming of the gun is performed using two retroreflective markers on the gun. The system records total walking time, shots fired, enemies/explosives hit and civilians hit. Subjects work up to 10 minutes of walking in this scenario, with treadmill speed and platform movement increased as ability of the subject increased.

Finally, patients participated in the Boat Slalom application. During this application, patients navigate a virtual boat through a slalom course (Fig. 2d). The platform movement moves in sync with the boat and wave motion. Subjects control the boat with two retroreflective markers placed on their shoulders. The CAREN system uses these markers to identify the location of the patient on the platform. Patients control their speed by moving anterior or posterior from their initial position on the platform. Left and right turns are accomplished by leaning respectively from their neutral starting position. Running in to an object (buoys, land masses) is registered as a collision and the subject must redirect himself. The system records a score which incorporates time to finish the course, objects hit (penalties) and the difficulty of the course settings (wave height and speed, which are increased as subject ability improves).

III. RESULTS

Table 1 summarizes the objective and subjective balance and gait measures. Posturography (SOT) improved in 3 out of 4 subjects within 6 weeks. In Subjects #2 and #3, pre-therapy functional gait (FGA) scores put them in a fall risk category (scores <26). After therapy, all patients normalized to the best possible FGA score. Two patients achieved this goal in 3 weeks at the midterm balance assessment. During initial CAREN therapy sessions, all subjects chose relatively slow walking speeds (0.60-0.80 m/s) commonly seen in patient populations. By the last therapy session, subjects chose speeds closer to normal, healthy adult walking speeds (~1.2 m/s).

Prior to therapy, all subjects had a significant dizziness handicap (DHI) rated as needed balance therapy, and lacked balance confidence (ABC) in their daily activities. After therapy, all subjects had increased confidence scores, with 3 out of 4 subjects achieving an ABC score above 86% (a percent measurement of how confident they feel doing certain activities). Those same subjects notably reduced

TABLE I. BALANCE AND GAIT MEASURES

Subj	SOT		FGA		ABC (%)		DHI	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	72	74	27	30	66	70	61	44
2	56	60	23	30	84	94	37	8
3	74	52	23	30	64	86	46	12
4	65	87	27	30	69	91	26	2

Individual data shown for subjects 1-4 for Pre- and Post-therapy

their DHI scores to below a threshold (>16) that classifies them as having a handicap. The remaining subject (Subject #1) decreased his DHI score from 61 (severe handicap) to 44 (moderate handicap).

All subjects showed improvements in dynamic visual acuity testing and the gaze stabilization test and target tracking (Table 2). After 6 weeks of therapy, all subjects improved target following with 2 out of the 4 subjects reaching 15 degrees of movement per second. On the DVAT, all subjects improved their visual acuity (lower LogMar number). A score below 0.20 is considered a healthy dynamic visual acuity test. Similarly, all four subjects improved their GST degrees per second. Prior to the training Subject #4 was unable to complete the GST test for a score but improved to reportable levels after training in the CAREN system.

IV. DISCUSSION

Over approximately 6 weeks, each subject steadily improved their performance on the CAREN applications. We incrementally increased the difficulty and complexity of each application over the twelve visits. Post treatment, every patient showed improvement on balance, gait and visual measures. Functional gait scores showed the fastest improvement (< 3 weeks/ 6 visits). Fast improvements in gait likely resulted from the significant amount of time walking during all but the Boat Slalom application. The ability of the CAREN system to simultaneously apply cognitive and physical loads on the patient increases the efficacy of each therapy session.

The current study shows the effectiveness of virtual environments as a therapeutic tool for mild traumatic brain injury. This form of therapy provides a novel approach that

can be highly motivating in young patient populations. Increased motivation, in conjunction with the complex tasking in virtual environments, could expedite recovery. Data from this patient population needs to be compared to those receiving traditional vestibular physical therapy for determination of differences in score and effectiveness.

V. CONCLUSION

The current study shows the effectiveness of virtual environments and treadmill walking as a therapeutic tool for mild traumatic brain injury. This form of therapy provides a novel approach that can be highly motivating in young patient populations. Increased motivation, in conjunction with the complex tasking in virtual environments, could expedite recovery.

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TABLE II. VISUAL ACUITY TESTING

	Target (deg/s)		DVAT (LogMar)								GST (deg/s)							
	Pre	Post	LD ₁	LD ₂	LU ₁	LU ₂	RD ₁	RD ₂	RU ₁	RU ₂	LD ₁	LD ₂	LU ₁	LU ₂	RD ₁	RD ₂	RU ₁	RU ₂
1	10	12	0.32	0.22	0.28	0.28	0.40	0.25	0.31	0.31	95	134	122	184	66	150	51	115
2	8	15	0.32	0.24	0.24	0.24	0.22	0.22	0.24	0.22	81	120	94	135	78	124	100	130
3	2	9	0.32	0.10	0.32	0.12	0.24	0.12	0.30	0.10	97	107	58	60	89	88	102	100
4	15	15	0.20	0.10	0.20	0.20	0.20	0.10	0.10	0.10	n/s	137	66	142	n/s	n/s	n/s	116

Individual data shown for subjects 1-4 for Pre- and Post-therapy target tracking (Target), dynamic visual acuity test (DVAT) and gaze stabilization test (GST). For a subject with no score on the GST, the term n/s is noted. For the DVAT and GST, data are listed for assessments in Left Down (LD), Left Up (LU), Right Down (RD) and Right Up (RU). Subscript numbers 1 and 2 respectively refer to assessments Pre- and Post-therapy.