A virtual reality approach to gait training in service members with lower extremity amputations

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ABSTRACT

Gait training is an essential part of the rehabilitation process for those with lower extremity (LE) amputations. For service members at Walter Reed Army Medical Center, the Computer Assisted Rehabilitation Environment (CAREN) allows virtual reality to be incorporated into gait training as an adjunct to conventional therapies. This retrospective case series examines the self-selected velocities achieved in two different virtual environments (VE) by 11 service members with LE amputations. These VEs allowed participants to progress from level walking to more challenging terrain. Over periods of four to eight weeks, all participants were found to increase their self-selected velocities; progression appears to be individual. The preliminary results obtained indicate that further investigation is warranted.

1. INTRODUCTION

As of March 2010, over 960 service members have sustained major limb amputations as a result of injuries incurred during Operation Iraqi Freedom and Operation Enduring Freedom. This population of service members consists of young, healthy men and women who maintained high levels of activity prior to their injuries and now have goals of achieving or exceeding prior fitness. For those with lower extremity (LE) amputations, approximately 80% of those affected, gait training is an essential part of the rehabilitation process (Esquenazi & DiGiacomo, 2001). Conventional gait training includes therapeutic exercises targeted at functional lower extremity strengthening, weight shifting over the prosthesis, and progressive ambulation. These techniques are applied to ambulation over level surfaces and then more challenging terrain. Depending on the severity of injury, assistive devices may be incorporated with the goal of maintaining quality of motion during ambulation. Research conducted on the efficacy of treatment programs, which have incorporated gait training and re-education for those with LE amputations, have shown improved symmetry in LE kinematics and kinetics, increased self-selected walking speeds, and decreased dependence on assistive devices (Sjodahl et al, 2001, 2002). These studies also found that positive training results remained after a period of six months. Thus, conventional therapies reach the goal of improving functional outcomes as well as producing a lasting effect in those with LE amputations.

The Computer Assisted Rehabilitation Environment (CAREN) [Motek BV, Amsterdam, The Netherlands] at Walter Reed Army Medical Center (WRAMC) allows virtual reality to be incorporated in the gait training of those with LE amputations in addition to conventional therapies. The CAREN is an instrumented treadmill embedded into a six degree-of-freedom motion platform that synchronizes in real time with a virtual environment (VE) projected onto a large, curved screen (Fig. 1). The CAREN is a new and unique device with less than a dozen systems in the world. The system at WRAMC is only one of five with an imbedded treadmill. Due to the rarity and cost of the system, CAREN based research is in its infancy and evidence based treatment recommendations are non-existent. However, promising results have begun to emerge with regard to the feasibility of the system for rehabilitation. In a study by Fung et al (2004), a VE for locomotor training was found to be feasible when utilizing a treadmill mounted on a CAREN motion platform. Using these combined technologies for gait training post-stroke, individuals with chronic stroke were observed to have improved control over gait speed (Fung et al, 2006). Another study concluded that healthy subjects were able to experience a strong sense of immersion during locomotor training with a virtual street scene (Yang et al, 2008). These studies illustrate that incorporating VEs with treadmill training has produced positive outcomes. However there is currently no published research on the efficacy of CAREN gait training for those with LE amputations.

The CAREN at WRAMC utilizes a safety stand and full body harness to provide a safe, controlled environment for gait training. Since the treadmill does not include handrails, participants cannot compensate with upper body support and must focus on LE motion. The motion platform has the capacity to allow for and vary inclines, declines and side slopes, which cannot be easily replicated in conventional, indoor therapy settings. The system also permits the settings (e.g. velocity and slope) of each VE to be systematically adjusted to increase or decrease the challenge of each activity; settings are recorded so that the progress of each individual can be followed. Through use of different VEs, the system has the potential to introduce and refine skills that may be encountered in real world situations. The purpose of this retrospective case series is to determine the feasibility of using the CAREN as an adjunct to conventional therapies, for gait training, in individuals with LE amputations. This study also seeks to establish whether a large-scale prospective study is justified. CAREN outcomes of service members, who participated in CAREN clinical rehabilitation sessions, will be examined.

2. METHODS

2.1 Participants

Retrospective chart reviews were performed on 11 service members with traumatic LE amputations; seven unilateral and four bilateral. Table 1 provides an overview of the specific diagnosis and age of each participant; those with similar diagnoses were grouped together. All were male with an average age of 28.9 ± 5.2 years.

Table 1. *Participant diagnosis and age.*

Group	Participant	Diagnosis	Age
1	P1	R – TT	27
	P2	L – TT	27
	P3	L – TT	33
	P4	R – TT	30
	P5	L – TT	21
	P6	L – TT	39
2	P7	R – TF	23
3	P8	R – Midfoot; L – TT	29
	P9	R – Knee disarticulation; L – TT	27
4	P10	Bilateral TF	27
	P11	Bilateral TF	35

R = Right; L = Left; TT = Transtibial; TF = Transfemoral

2.2 Equipment

The CAREN Laboratory at WRAMC has a six-degree-of-freedom motion platform that is 3 meters in diameter (Fig. 1). The platform has the ability to translate approximately 1 meter and rotate up to 18 degrees in any direction. It contains an embedded treadmill, approximately 1.5 meters long by 1.0 meter wide, which has a maximum velocity of 5 m/s. The platform works in combination with a 12 camera motion capture system (Vicon Inc., Oxford, UK) which allows for real time synchronization and interaction with the VEs. VE images are projected onto the 120 degree curved screen, approximately 2.5 meters high by 4.5 meters wide, via two projectors (3D Perception, Asker, Norway) which are blended together to form a single, continuous image. A surround sound audio system may also be utilized. Safety is ensured through the use of a full body harness system.

2.3 Virtual Environments

CAREN gait training at WRAMC incorporates a variety of different VEs. However for the purposes of this case series, outcomes are only reported for the Continuous Road and Road with Overhead Targets applications. These gait applications allowed participants to progress from level walking to inclines, declines, and side-slopes. Both VEs were created using the CAREN D-Flow Software with graphics created in SoftImage (SoftImage Co., Montreal, Canada).

Figure 1. *Participant walking on the CAREN system during the Continuous Road VE.*

The Continuous Road provided an introduction to locomotion on the CAREN system. This VE began with level walking and allowed each participant to establish a comfortable pace. Once pace was established, the velocity, duration of activity, and grade of platform slope were adjusted based on the recommendations of the treating therapist. To provide the participants with real-time feedback, time and velocity were visually displayed on the screen in their periphery.

The Road with Overhead Targets focused on full body coordination. Reflective markers were placed on the participants' hands so that they could interact with the VE by hitting overhead targets, appearing at random intervals, while walking or jogging over uneven terrain. This terrain included inclines and declines of varying degrees and duration. Time, velocity, and the number of targets hit were displayed.

2.4 Procedures

All participants were referred to the CAREN by their primary physical therapists for clinical rehabilitation. The frequency of visits was determined by the referring therapist and depended on the participant's availability. Each participant was typically scheduled for one or two sessions per week; sessions were 30 minutes in length. Since there were often breaks in rehabilitation to allow for prosthetic changes or to undergo and/or heal from surgical procedures, only participants seen regularly for four to eight consecutive weeks were included in this case series.

Each participant's starting point and progression in the CAREN varied according to their level of injury and phase of rehabilitation. During their initial CAREN session, functional goals were discussed with the referring therapist and the VEs that would be most appropriate for the participant were identified. Consequently, not all participants took part in the same applications. Sessions were divided between treadmill VEs and those considered pre-gait (i.e. weight/step shifting). Too much of any one application type (weight/step shifting or treadmill) has been subjectively reported to cause residual limb pain in prior patients with LE amputations. For all VEs, participants were required to wear a fully body harness and were tethered securely to the CAREN safety stand.

For the Continuous Road and Road with Overhead Targets, participants were instructed to walk at a comfortable pace. The speed of the treadmill was slowly increased until the participant indicated that their desired self-selected velocity had been reached. Participants were given verbal cues by the treating therapist during each application to ensure that quality of motion was maintained. If necessary, the velocity of the treadmill was increased or decreased based on feedback from the treating therapist. The final velocity achieved was recorded for each completed application attempt. Since the Continuous Road had no definitive end, the treating therapist determined when the application was complete. However, for the Road with Overhead Targets the application was considered complete when the patient reached the end of the pathway.

3. RESULTS

3.1 Continuous Road

For the Continuous Road, the velocities for only the first three completed application attempts were examined. This was due to participant progression to the more challenging gait applications, adjustment time required for prosthetic changes, or for surgical procedures. All participants were shown to increase their self-selected velocity for each successive attempt (Fig. 2). The percent change observed for the second and third attempts as compared to the first also increased (Table 2). Participants with bilateral TF amputations, P10 and P11, had the slowest initial velocities at 0.18 m/s and 0.22 m/s respectively. However, P11 showed the greatest overall percentage increase at 44.4% when comparing the third attempt to the first. P2, with a unilateral TT amputation, achieved the highest initial velocity as well as the highest velocity after the third attempt. With an initial velocity of 1.16 m/s and a final velocity of 1.96 m/s, the overall change observed for P2 was 40.91%.

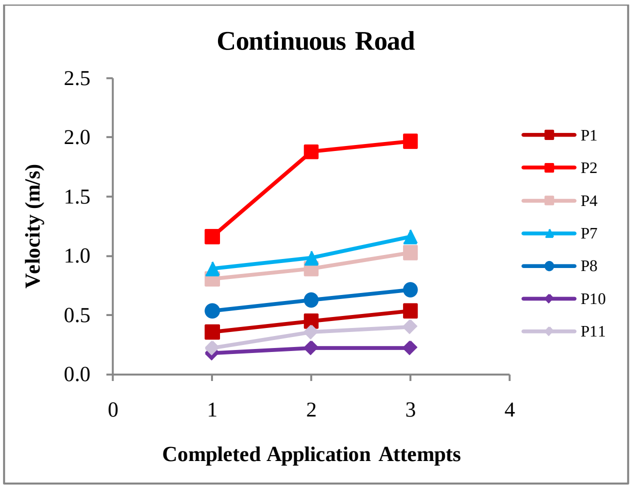

Figure 2. *Velocities (m/s) achieved by each participant for the Continuous Road VE.*

Table 2. *Percent change observed for velocity in the Continuous Road VE.*

	Attempt Comparison	
Participant	**2 vs. 1**	**3 vs. 1**
P1	20.0	33.33
P2	38.1	40.91
P4	10.0	21.74
Group 1 Average	**22.7**	**32.0**
P7	9.91	23.08
Group 2 Average	**9.91**	**23.08**
P8	14.29	25.0
Group 3 Average	**14.29**	**25.0**
P10	10.0	21.74
P11	37.5	44.44
Group 4 Average	**23.75**	**33.09**

3.2 Road with Overhead Targets

For the Road with Overhead Targets, up to five completed application attempts were reported for each participant (Fig. 3). Increased velocities were observed for all participants for the first three attempts. Only P8 and P9, with bilateral TT amputations, were found to decrease in velocity after the third attempt. Even still, the velocities achieved during those final two attempts, were greater than those achieved during the initial attempt. P8 had an initial velocity of 0.49 m/s and a final velocity of 0.63 m/s. P9 had an initial velocity of 0.89 m/s and a final velocity of 1.34 m/s. P5, with a unilateral TT amputation, experienced the greatest change in velocity, 61.36%, when comparing the fifth attempt (1.97 m/s) to the initial (0.76 m/s). The percent changed observed for all participants can be seen in Table 3.

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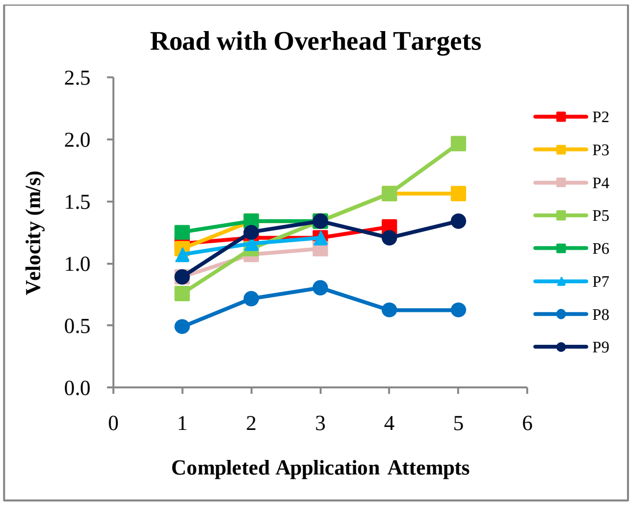

Figure 3. *Velocities (m/s) achieved by each participant for the Road with Overhead Targets VE.*

Table 3. *Percent change observed for velocity in the Road with Overhead Targets VE.*

	Attempt Comparison			
Participant	**2 vs. 1**	**3 vs. 1**	**4 vs. 1**	**5 vs. 1**
P2	3.7	3.74	10.35	--
P3	16.67	16.67	28.57	28.57
P4	16.67	20	--	--
P5	32.0	43.33	51.43	61.36
P6	6.67	6.67	N/A	N/A
Group 1 Average	**15.14**	**18.07**	**30.12**	**44.97**
P7	7.69	11.11	--	--
Group 2 Average	**7.69**	**11.11**	**--**	**--**
P8	31.25	38.89	21.43	21.43
P9	28.57	33.33	25.93	33.33
Group 3 Average	**29.91**	**36.11**	**23.68**	**27.38**

4. DISCUSSION

These preliminary results indicate that CAREN gait training may contribute to greater self-selected velocities for those with LE amputations. However, since the CAREN is currently utilized as an adjunct to conventional gait training techniques, additional research must be conducted to further examine the benefits of this new technology for this purpose.

This case series shows that over periods of four to eight weeks all participants demonstrated increased velocities for the Continuous Road and Road with Overhead Targets. Those with unilateral TT amputations tended to have greater self-selected velocities than those with higher levels of amputation. However, the different progressions observed within each participant group indicate that even with the same diagnosis progression is individual. This is especially true when comorbidities are present. Among the unilateral TT participants, P4 was observed to have lesser changes which may have been due to persistent back pain and P1 had limited range of knee motion due to heterotopic ossification. The only participant with a unilateral TF amputation (P7) had severe LE injuries on his intact side.

For the participants that took part in both VEs (P2, P4, P7, P8), it was observed that the uneven terrain and overhead distractions in the Road with Overhead Targets caused some participants to be more conservative with their self-selected velocity as compared to the Continuous Road. P2 (L - TT) and P8 (R - Midfoot, L - TT) achieved higher velocities in the Continuous Road VE, while P4 (R - TT) and P7 (L - TF) surpassed their prior self-selected velocities. Neither of the participants with bilateral TF amputations took part in the Road with Overhead Targets application. Both participants had trouble with socket fit and were not seen again until after the four to eight week period covered in this case series. However, upon their return, each was able to successfully complete the application.

Based on the growing number of clinical referrals it can be inferred that the CAREN has been well-received by participants and therapists. Referring physical therapists have subjectively reported that CAREN gait training has benefited participants by improving confidence and endurance, decreasing reliance on assistive devices, and improving weight shifting over the prosthesis. Improvements have also been noted in overall stride symmetry and in negotiating inclines and declines. The incorporation of a CAREN specific subjective questionnaire in future studies could help to substantiate this feedback and determine whether using the CAREN for gait training does indeed provide practical information to therapists and participants.

Despite the small sample size of this retrospective study, the positive trends identified with regard to self-selected velocity indicate that further investigation of the efficacy of CAREN gait training is warranted for this patient population. A prospective study with a larger sample size could validate this training method and determine whether it helps to facilitate the acquisition of goals by providing additional treatment recommendations for those with LE amputations. Future research could be more structured, controlling for variables such as slope and duration. Kinematic and kinetic data could also be included as well as other conventional outcome measures (e.g. Dynamic Gait Index, 6 Minute Walk, etc.). Unfortunately, in this case series no kinematic or kinetic data was reported because marker sets are minimized for clinical rehabilitation sessions in the CAREN.

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