Evaluating the Gait of Lower Limb Prosthesis Users

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Abstract Outcome assessments are vital in facilitating periodic, episodic and ongoing evaluation of persons with limb loss. There are many outcome measures used to quantify prosthetic fit, alignment, comfort, functionality and usability of lower limb prostheses. However, many measures are subjective, difficult to implement in a clinical setting and lack psychometric evaluation. This study used an immersive Computer Assisted Rehabilitation Environment (CAREN) virtual reality system with an instrumented spilt-belt treadmill and real time motion capture system as a research tool to evaluate and compare the gait of lower limb prosthesis users and non-amputees as a preliminary study to determine the effectiveness and appropriate use of outcome measures. The use of the CAREN system providing more real world scenarios such as ramps, inclines and unexpected inclines helped evaluate the hill assessment index (HAI) and the combined gait asymmetry metric (CGAM).

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1 Introduction

Lower limb amputations are prevalent in the U.S., often due to complications from vascular issues caused by diseases such as diabetes as well as trauma from war related injuries or motor vehicle accidents [1]. In the United States, there are more than 2 million people who have lost a limb and that number is expected to double by 2050 [1]. On average the healthcare costs are $500,000 per person over a 5-year period following limb loss, and additional prosthesis costs over the 5-year period can reach $450,000, with additional rehabilitative costs [1]. Prostheses are often rejected or underused due to problems with control, function, training, comfort or fit. The prevalence and expenses involved in lower limb amputations necessitate specific and effective tools and outcome measures for prosthesis prescription, evaluation and rehabilitation. Outcome assessments are vital in facilitating periodic, episodic and ongoing evaluation of persons with limb loss. Third party reimbursors are demanding justification and evidence for payment of services. There is a need for valid and reliable outcome assessments to quantitatively measure prosthetic fit and patient performance.

The Hill Assessment Index is a 12 level ordinal scale developed to address different characteristics of hill ascent and descent but is a high subjective measure [2]. Learning how a prosthetic leg functions on inclines and declines may assist with prosthetic design and training. Measuring asymmetry of prosthetic gait is also of great importance to prosthesis designers, users and therapists. Most amputees have many asymmetric biomechanical parameters including spatial, temporal, kinetic and kinematic. This is because of the inherent asymmetric change in force and motion capabilities in their limbs. However, kinematic and dynamic symmetry is not possible in an asymmetric system [3], and symmetry may not even be necessary for a gait to be considered normal and unimpaired [4]. Since individuals with amputations are inherently asymmetric, aiming for a gait pattern close to that of a symmetric person may not the ideal approach. To understand how multiple parameters interact, we use the Combined Gait Asymmetry Metric (CGAM) to represent the level of asymmetry using five gait parameters [5].

2 Methods

2.1 *The CAREN System*

The CAREN system (Fig. 1) consists of D-Flow control software, a 180º projection screen and projectors, a 6-degree of freedom platform with a built-in instrumented dual-belt treadmill, and 10 Vicon motion capture cameras. Reflective markers were positioned according to the Vicon Plug-in-Gait lower limb model and motion capture data were processed in Vicon Nexus. An YXZ cardan sequence with two

Fig. 1 Bilateral transtibial amputee walking on the CAREN system

proximal segments was used to calculate joint angles. In order to compare hip, knee, and ankle flexion of all participants, gait trials were normalized to percent of the gait cycle

2.2 Data Collection and Analysis

A testing protocol (IRB # Pro00018519) was approved by the University of South Florida's Institutional Review Board to collect data with the CAREN while non-amputees and amputees walk on a treadmill at a self-selected speed at various elevations and with unexpected gait perturbations.

Two preliminary studies using the CAREN system to evaluate and compare the gait of lower limb prosthesis users were completed. Five non-amputees, four females and one male with a mean age 26 yr ± 10 participated and one bilateral transtibial amputee (TTA), a 50 year old diabetic male, 15 (leg 1) and 13 years (leg 2) post-amputation participated in the first study. Gait trials included walking on level ground, 5° incline and decline, and a ±3° cross slope for able-bodied and ±2° cross slope for the bilateral amputee. The methods for non-amputees in [6] were similar for the amputee.

A second preliminary study was conducted with one non-amputee participant and one 37 year old female with a right unilateral transfemoral amputation fitted with two different socket designs: the IRC and VAS brimless. In order to understand how multiple parameters interact, the Combined Gait Asymmetry Metric (CGAM) was used to represent the level of asymmetry using five gait parameters. In addition to typical walking, the five randomized scenarios were foot slip, tread deceleration, missing step (4° pitch), height change (±5° roll), and unstable ground. The perturbations utilized the split belt treadmill and were performed at three speeds of 0.5, 0.9, and 1.3 m/s. The perturbations were randomized to prevent anticipation by the subject.

3 Results

For the first study, average hip, knee (Fig. 2), and ankle flexion were calculated illustrating a comparison between elevations, as well as a comparison between non-amputee and amputee gait. The bilateral TTA demonstrated significantly reduced flexion compared to the non-amputees across all joints and phases of the gait cycle. The greatest difference occurred in knee flexion where the non-amputee maximum across all elevations was approximately 60° and the amputee maximum was approximately 40°. Hip extension was also about 10° less across all elevations for the TTA and hip hiking was evident during the swing phase. Lastly, there was a reduction in both ankle dorsi and plantar flexion for the TTA. This was to be expected as the amputee did not use a multi-axial prosthetic foot.

For the second study, the gait biomechanics with spatial, temporal, kinematic, and kinetic parameters are used to calculate the CGAM. Both prosthetic gaits showed a higher magnitude compared to the able-body gait, as expected. The CGAM was calculated for all perturbations at each speed and are presented for walking at all three speeds. These speeds are shown for comparison to our earlier experiment on able-bodied subjects at the same speeds. Figure 3 depicts the CGAM magnitudes with the respective sockets and speeds.

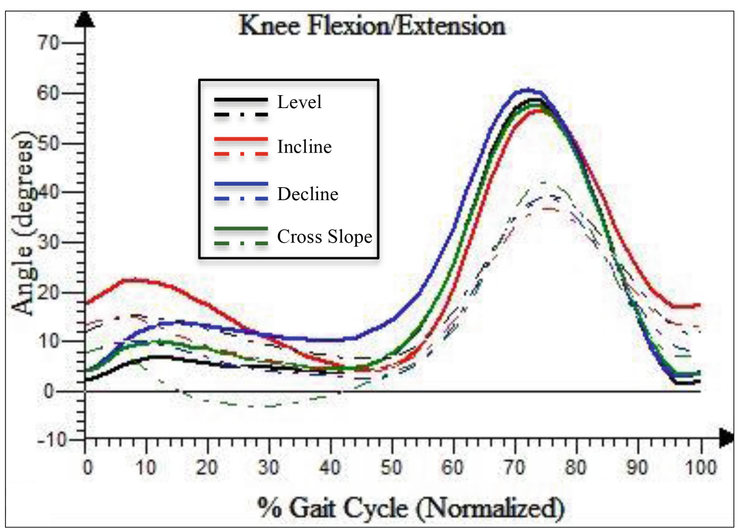

Fig. 2 Average knee kinematics at various elevations: level (black), uphill (red), downhill (blue), and cross slope (green) walking in non-amputees (solid) and bilateral transtibial amputee (dashed)

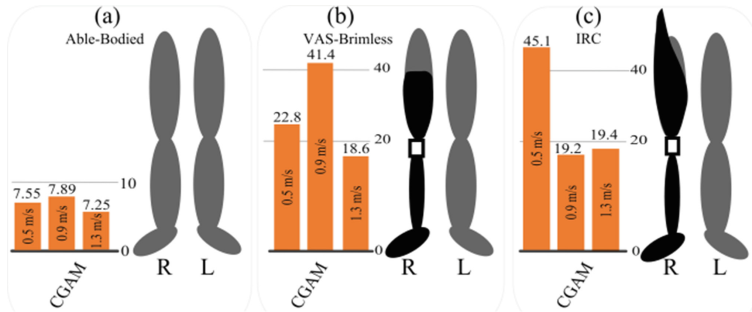

Fig. 3 Combined Gait Asymmetry Metric magnitudes for **a** Able- Body subjects, **b** Gait with VAS-Brimless Socket, and **c** Gait with IRC Socket

4 Discussion

Providing objective data on how lower limb prosthetic function at various inclines and side slopes will aid in benchmarking to improve prosthetic design and training. These data showed the differences in hip, knee, and ankle kinematics at various elevations with the CAREN, as well as a comparison between normative and bilateral transtibial amputee gait. This information can improve upon subjective outcome measures such as the HAI.

CGAM is a quantifiable single number representing gait quality that could serve as a clinical measure of biomechanical parameters of gait rather than a qualitative and subjective perspective. In this presented comparison between sockets and able-bodied individuals, it was demonstrated that there are differences in asymmetry and reducing the CGAM magnitude will result in an improved gait pattern.

5 Conclusion

This work demonstrated that the CAREN can be used to measure the functional status of an amputee. Future studies with more subjects will examine outcome measures that can be used to track ability, test different devices, and demonstrate the patient's need for specific types of prostheses. The effects of various prosthetic components and rehabilitation interventions can also be evaluated.

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