PRELIMINARY VALIDATION OF TRANSFEMORAL PROSTHETIC GAIT SIMULATOR

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INTRODUCTION

When a device to improve the functionality of existing assistive devices is newly designed for patients with mobility impairment, the efficacy of the device needs to be evaluated. During initial prototype evaluations, collecting experimental data from actual patients might be challenging due to limited mobility to access a laboratory and possible secondary conditions prevalent among patients with mobility impairment [1]. Therefore, experiments would be conducted more safely and efficiently if individuals without mobility impairment could perform given simulated motor tasks affected by the impairment. However, the premise is that the tasks accurately represent the characteristic performance of the patients with mobility impairment. For example, unilateral transfemoral prosthetic gait (TPG) is characterized by lower self-selected speeds, shorter prosthetic stance phase, extended knee during stance phase, and increased hip flexor activity [2, 3, 4, 5].

In this study, simulated unilateral TPG performance using an in-house TPG simulator was evaluated. A previous study using a TPG simulator has shown that gait kinematics such as joint angles and stride length parameters are consistent with the data obtained from actual patients [2]. However, up to this date EMG during simulated unilateral TPG has not been analyzed. Therefore, the current study examined hip and knee angles and EMG from four muscles in the simulated prosthetic leg to compare with published data of actual transfemoral amputees.

METHODS

Simulator Fabrication: The TPG simulator was constructed using a set of a mechanical knee, an aluminum pylon, a Niagara foot (Limbs Relief Knee LimbBox, Limbs Int., El Paso, Texas), and a connector (socket) constructed from a sheet of 2-mm thick stainless steel bent into a U-shape to fit around the thigh. A leg brace locked at 110-degree knee flexion was used to immobilize the subject's lower leg and to securely attach the simulator to the subject's leg. The user wore a knee pad with Velcro to secure the knee in place with the connector (Fig.1).

Figure 1. Fabricated TPG simulator

Subjects: Two college students participated in this preliminary study. Both subjects had no prior experience with the simulator and acclimatized themselves to the simulator until they were able to walk down a 30 m track at 60% of their normal gait speed [6]. Subjects wore their own athletic shoes for testing.

Testing: 34 reflective markers were attached to anatomical landmarks of the pelvis, legs and feet including the simulator. Using a motion capture system with 7 infrared cameras (T10, VICON, Oxford, UK), kinematic data were captured at 100 Hz during 6-m walk aiming at a target speed of 1.0 m/s, while the subject wore the TPG simulator on his/her dominant leg. The target speed was selected to compare with previous studies using mechanical knees, showing self-selected speeds at or near 1.0 m/s [2, 3, 4]. Five trials were performed for each subject. Wireless surface EMG electrodes (Trigno, Delsys Inc., Natick, MA) were placed on the following muscles in the simulated prosthetic limb: the tensor fasciae latae, gluteus medius, rectus femoris, and semitendinosus [5]. EMG signals were sampled at 1 kHz.

Data Processing: Custom-written codes using MATLAB (v8.1, MathWorks Inc., Natick, MA) were used to calculate joint angles and process the EMG data. The kinematic data of all trials of each subject were time-normalized to a full gait cycle and averaged. EMG data were low-pass filtered (10 Hz), rectified, and band-pass filtered (10-400 Hz) to generate EMG linear envelopes, then time-normalized to a full gait cycle. After taking intra-subject average, the EMG magnitude was normalized to the maximum value over the gait cycle.

RESULTS AND DISCUSSION

The subjects were able to walk at the speeds near the target speed (1 m/s) after acclimatization (Table 1). The stride length was comparable to a previous study (1.26±0.14 m) with similar gait speed (0.82±0.11 m/s) [2].

Table 1: Subject data. Mean gait speed and stride length parameters ± 95% CI interval.

	Subject 1	Subject 2
Gender	Female	Male
Age (yrs)	21	21
Height (cm)	162.6	172.7
Weight (kg)	59.0	87.5
Acclimatization Time (hr)	3.25	1.5
Gait Speed (m/s)	0.85 ± .05	0.97 ± .09
Stride Length (m)	1.19 ± .05	1.13 ± .05

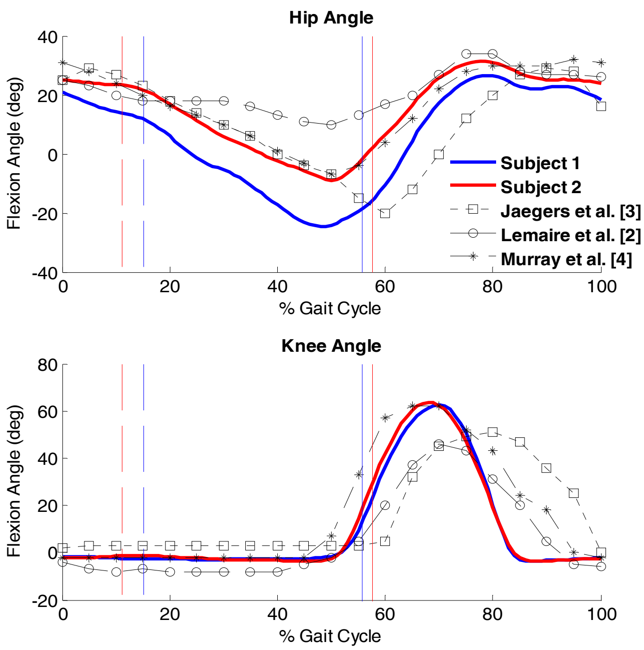

Figure 2: Hip and knee angles of simulated prosthetic leg over a gait cycle. Data ensembles the average of all trials. Vertical solid lines indicate the ipsilateral toe-off, and dashed lines indicate the contralateral toe-off.

The joint kinematics of the prosthetic leg (Fig. 2) were in general similar to the literature [2, 3, 4]. Subject 1 showed more extended hip positions during the stance phase, which may be due to the subject attempting to maintain the target speed with shorter single stance duration on the prosthetic side. EMG patterns in Fig. 3 also exhibit similar trends between subjects and a previous study that exhibited large variability in EMG among three transfemoral amputees [5].

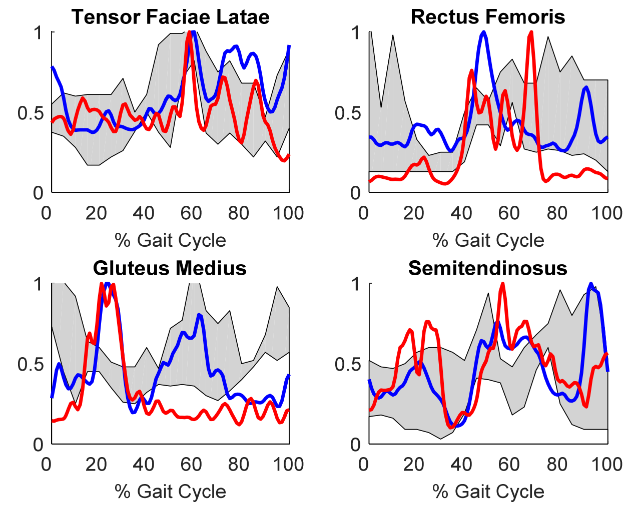

Figure 3: EMG linear envelopes over a gait cycle. Blue and red lines represent Subject 1 and Subject 2, respectively. The shaded area represents the range of EMG obtained from three transfemoral amputees in Wentink et al. [5].

CONCLUSIONS

These preliminary results showed that simulated TPG using the developed simulator may be used to evaluate the efficacy of prototype devices aiming to improve the functionality of existing assistive devices such as prosthetic knees. Collecting data from a larger number of subjects and other biomechanical and physiological data is planned in the future study for further confirmation.

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