NEUROMOTOR ADAPTATIONS USED BY UNILATERAL TRANSTIBIAL AMPUTEES DURING NORMAL WALKING

Michael Neal 1, Richard R. Neptune 2 and Andrew Gitter 3,4
1 Department of Biomedical Engineering, University of Texas, Austin, TX
2 Department of Mechanical Engineering, University of Texas, Austin, TX
3 Department of Rehabilitation Medicine, University of Texas Health Science Center, San Antonio, TX
4 South Texas VA Medical Center, San Antonio, TX
E-mail: rneptune@mail.utexas.edu

INTRODUCTION
Unilateral transtibial amputation results in the loss of ankle muscle function and joint movement as well as modified mechanical properties in the residual limb. The muscles crossing the ankle joint have been shown to be important contributors to normal walking mechanics including body support, forward progression and swing initiation (Neptune et al., 2001). As such, significant neuromotor adaptations would be expected in order to restore normal walking mechanics, although it is not clear what adaptations would be necessary. Most, but not all amputees adapt their neuromotor strategies in such a way that they achieve relatively normal walking kinematics. Understanding how successful amputees achieve relatively normal walking mechanics may provide insight into designing effective prosthetic devices and rehabilitation strategies to improve their gait mechanics and accelerate recovery. Therefore, the objective of this study was to collect EMG data from the intact and residual limbs to identify how proficient amputee walkers adapt their neuromotor patterns to achieve relatively normal walking mechanics, which was defined based on symmetric walking kinematics.

METHODS
Eight traumatic unilateral transtibial amputees (seven males, one female) free from additional musculoskeletal disorders and five healthy normal subjects serving as controls (5 males) participated in this study. Informed consent was received before participation in the study. Muscle EMG activity in six intact limb muscles (tibialis anterior, soleus, medial gastrocnemius, vastus medialis, rectus femoris, biceps femoris long head) and three residual limb muscles (vastus medialis, rectus femoris, biceps femoris) were recorded using surface EMG electrodes. The subjects were asked to walk multiple trials at a speed of 1.3 m/s. The amputee subjects used their own prosthetic foot (7 energy storage and return, 1 SACH). The EMG signals were full-wave rectified, low-pass filtered and normalized to the maximum value observed in each muscle across all trials. Simultaneously, motion capture data was collected (Vicon 370 Workstation) using a modified Helen Hayes marker set to generate joint kinematic trajectories over the gait cycle. Foot switches were used to provide temporal timing for the EMG data. All data were averaged across trials for each subject, and then averaged across subjects. Both the group and individual average trajectories were analyzed to identify the neuromotor strategies used by the amputees.

RESULTS AND DISCUSSION
All subjects were proficient walkers with symmetrical and smooth kinematic trajectories similar to the healthy control subjects (Fig. 1). As a group, the primary neuromotor adaptations were 1) a larger and more prolonged burst of vasti (VAS) activity in both the intact and residual limbs beginning in pre-swing and 2) prolonged ankle plantarflexor activity during the stance-swing transition. These adaptations were consistent with the observed increase in the knee extensor moment in pre-swing (e.g., Nolan
and Lee, 2002) and greater power output from the intact limb needed for forward propulsion, respectively. All other muscles were similar between the amputee and control groups.

![Hip Angle](image1.png)

**Fig. 1:** Hip and knee joint kinematics for the amputee and normal groups. Differences were observed in the ankle joint during swing as expected (not shown).

Similar to normal subjects (Wootten, 1990), distinct variations in neuromotor strategies were present in individual amputees that were masked by the group averaging. For example, Subject A used a prolonged burst of intact limb soleus (SOL) activity in pre-swing, while using relatively normal intact limb VAS activity (Fig. 2). In contrast, Subject B used a different strategy with a relatively normal SOL pattern and a late burst of VAS activity in pre-swing (Fig. 2). SOL activity in pre-swing has been previously shown to provide body support and forward progression (Neptune et al., 2001). The present results suggest that VAS and SOL may be co-functional and have the same body segment energetic effect during this region, and thus provide an alternative strategy for the amputees to satisfy the task requirements. Differences in neuromotor strategies were also evident in both the intact and residual limb biarticular hamstring and rectus femoris muscles.

![SOL Activity](image2.png)

**Fig. 2:** SOL and VAS activity over the gait cycle for two amputees and the control group.

**SUMMARY**

The amputees analyzed in this study were proficient walkers with symmetric gait kinematics. Both as a group and individually, altered patterns of EMG activity were present reflecting the use of adaptive neuromotor strategies to compensate for the lost ankle function and altered mechanical properties in the residual limb. Individual amputees adopted differing neuromuscular strategies that all lead to the recovery of successful ambulation. The potential advantages associated with the different strategies are unknown, likewise it is unclear if adverse consequences exist that may increase metabolic cost or increase muscle/joint loading that may lead to musculoskeletal disorders. Future work will be directed at using musculoskeletal modeling and dynamic simulations to understand how these individual neuromotor strategies are used to satisfy the task requirements, potential consequences of using such strategies, and how they vary with prosthetic components.

**REFERENCES**

