Initial Experimental Study on Dynamic Interaction Between an Amputee and a Powered Ankle-Foot Prostheses

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INTRODUCTION

Today, commercially available ankle-foot prostheses are completely passive, and consequently, their mechanical properties remain fixed with walking speed and terrain. Conversely, normal human ankle stiffness varies within each gait cycle and also with walking speed [1][2][3]. Furthermore, some studies have indicated that one of the main functions of the human ankle is to provide adequate energy for forward progression of the body [1]-[4]. Thus, an ideal ankle-foot prosthesis should be able to actively control joint impedance, motive power, and joint position. Understanding the dynamic interaction between an amputee and an active prosthesis is critical to developing truly functional leg prostheses. For this reason, we have developed a novel robotic ankle-foot emulator (Figure 1) [5]. The emulator is capable of changing mechanical impedance and providing sufficient mechanical energy for forward propulsion. In this paper, we present pilot data on the actual interaction between an amputee and the ankle emulator during walking. These data support the hypothesis that actively controlling ankle joint impedance may provide a more natural gait than a conventional passive prosthesis. Furthermore, adding additional mechanical energy beyond that a passive spring ankle can provide during powered plantar flexion can dramatically increase the self-selected walking speed of an amputee.

METHODS

We tested the device on a healthy, bilateral below-knee amputee that wore the emulator on his right leg and a conventional passive below-knee prosthesis on the left leg. The amputee participant was requested to walk along a 6 foot-long walkway at a self-selected speed. During the experiment, the emulator was programmed as a linear torsional spring with two different stiffness values which are K_{CP} and K_{CD}, respectively. The stiffness of the emulator changed from one value to another when the ankle angle passed through zero degrees (Mid-Stance). He communicated desired stiffness values to a separate operator during the walking trials. One of the objectives of this study was to obtain the preferred stiffness values K_{CP} and K_{CD} of the subject. Additionally, the amputee was supplied a switch to control the timing at which an additional impulse of force was applied to the body ("push-off") during each gait cycle.

RESULTS AND DISCUSSION

From the experiment, we observed that the emulator behaved more naturally than the conventional passive prosthesis. Based on the subject's comments, the

Fig. 1 A prototype of the robotic ankle-foot emulator.

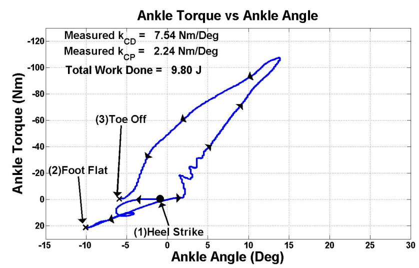

Fig. 2 Measured ankle torque-angle plot of the emulator of one gait cycle. The plot began at heel-strike and ended at toe-off of the gait cycle. The area enclosed by the curve represents the work done at the joint. The amputee's walking speed was dramatically increased in the experiment because the emulator added an additional amount of mechanical energy into the body in each gait cycle.

virtual spring K_{CP} improved shock absorption during heel-strike and also allowed for a smoother transition from CP to CD.Not surprisingly, the subject selected a stiffness value K_{CP} that eventually converged to the normalized biological value, which is about 2 Nm/deg [1][2].

Besides, adding an additional amount of mechanical energy to the amputee could substantially increase the self-selected speed of the study participant. The study participant reported that the best timing for adding additional power to the body from the emulator was at the moment when the heel of the adjacent foot had initial contact with the ground.

CONCLUSIONS

The initial experiments support the hypothesis that the emulator can provide a more natural gait than a conventional passive prosthesis. Based on the subject's report, adding an additional amount of mechanical energy to the amputee can substantially increase the self-elected speed of the study participant.

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