THE EFFECTS OF SPRINT SPEED ON APPARENT STIFFNESS IN UNI-LATERAL TRANS-TIBIAL AMPUTEE SPRINT RUNNERS

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INTRODUCTION

Recent research suggests that the ability to generate force limits top speed in humans with intact limbs [1, 2]. A number of high-speed sprint running studies have shown that as sprinters increase velocity, peak vertical ground reaction forces increase in magnitude and occur earlier during the stance phase (Fig. 1A) [e.g., 3]. This leads to an increase in eccentric stiffness, which describes the relationship between force and center of mass displacement from foot contact to peak force (Fig 1B)[4]. Preliminary data have shown a strong correlation between eccentric stiffness and stance averaged vertical ground reaction force, a key determinate for top running speed [1]. While eccentric stiffness increases with speed, the rate of force decline and concentric (unloading) stiffness, remain unchanged.

Recent data from an elite bi-lateral amputee, who uses running-specific prostheses designed to mimic the spring-like characteristics of biological limbs during running, shows that he achieves top speeds using different mechanical means than intact sprinters [3, 5]. Specifically, at top speed, peak vertical ground reaction forces are much lower for this bi-lateral amputee than for performance-matched intact sprinters [5], and unlike intact athletes, eccentric stiffness is nearly independent of running speed.

To better understand the mechanical effects of running-specific prostheses compared to intact limbs, we measured temporospacial and ground reaction force (GRF) variables of uni-lateral trans-tibial amputee sprinters over their full range running speeds. Uni-lateral amputees provide a unique opportunity because each amputee's intact limb serves as a control for comparing of the biomechanics between the biological limb and the residual plus prosthetic limb.

We hypothesized that eccentric stiffness would increase with increasing speed in the intact leg but would be independent of speed in the prosthetic leg, and that concentric stiffness would be independent of speed in both legs.

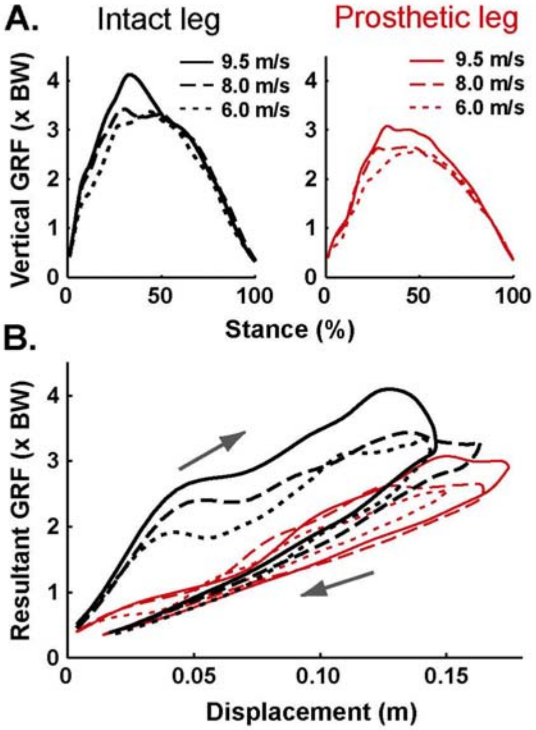

Fig 1. Representative traces from a single subject at three speeds. A) Stance normalized vertical GRF. B) Resultant GRF plotted against center of mass displacement. Eccentric stiffness is calculated from toe-on to peak force and concentric stiffness is calculated from peak displacement to toe-off.

METHODS

Six otherwise healthy unilateral trans-tibial amputee elite Paralympic sprinters (4 M, 2 F) participated in the study. All subjects gave informed written consent according to the approved Intermountain Healthcare IRB protocol. All of the experiments were conducted at the Biomechanics Laboratory of the Orthopedic Specialty Hospital .

Subjects performed a series of discontinuous constant speed running trials consisting of short running bouts of at least 10 strides. Data were collected on a custom-built, high-speed, 3D force sensing motorized treadmill (Athletic Republic, Park City, UT) at 1600 Hz and were filtered with a critically damped filter implemented using Visual 3D software. Subjects began each series of trials at 3 m/s and speeds were increased in 1 m/s increments until they reached ~ 75% of their maximal running speed. Speed was then increased in 0.2-0.5 m/s increments until subjects reached their top speed, determined as the speed at which they could no longer maintain their horizontal position on the treadmill. Subjects were given as much time between trials as needed for full recovery.

Instantaneous stiffness was calculated using a modified spring-mass model assuming a constant horizontal and angular velocity. Stiffness was calculated as the ratio of the resultant GRF and the resultant displacement of the center of mass. Eccentric stiffness was calculated from toe-on to peak force, while concentric stiffness was calculated from peak leg displacement to toe-off (Fig. 1B).

RESULTS AND DISCUSSION

The results of our study support our hypotheses. Eccentric stiffness increased significantly with increasing speed in the intact leg, but was independent of speed in the prosthetic leg (Fig. 2A). Additionally, eccentric stiffness was greater in the intact leg compared to the prosthetic leg at speeds of 7 m/s and higher. Concentric stiffness was independent of speed in both legs, and not significantly different from eccentric stiffness in the prosthetic leg (Fig 2B). Consistent with previous preliminary results, there was a significant correlation between stance averaged vertical GRF and eccentric stiffness.

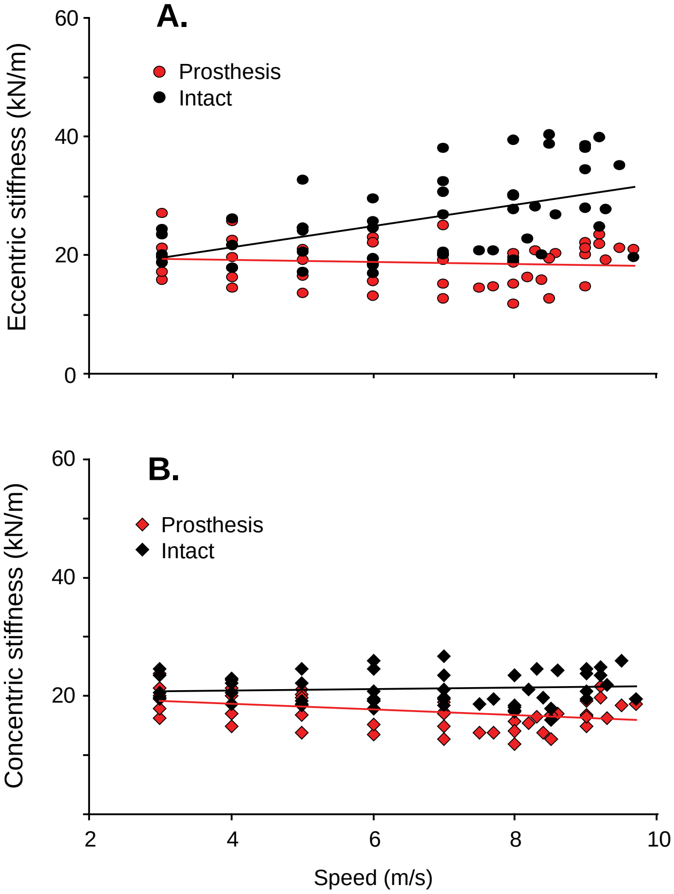

Fig. 2 A) Eccentric and B) concentric stiffness vs speed.

Our results suggest that the stiffness of the prosthetic leg is dominated by the passive mechanical properties of the prosthesis and cannot be modulated in response to speed in the same fashion as the biological leg. The correlation between eccentric stiffness and average vertical GRF suggests that a fixed stiffness prosthesis may limit the ability to produce high vertical GRF, especially at high speeds. Thus, in order to achieve similar top speeds as intact sprinters, athletes with prostheses must alter other aspects of running mechanics such as contact length or step frequency.

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