METABOLIC COST CHANGES WITH THE AMOUNT OF PROSTHETIC ANKLE POWER PROVIDED

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INTRODUCTION

The ankle plantarflexors produce roughly 80% of the mechanical power required for normal gait [1], yet current passive elastic prostheses only produce an eighth of this power [2]. Likely due to this deficit, people with transtibial amputation have a 10-30% greater metabolic cost for walking than non-amputees [3]. Active ankle prostheses that are able to accommodate for the functionally absent plantarflexors have improved metabolic cost during walking [4]. However, it is unclear whether directly matching the power of the intact limb would alleviate this plantarflexor deficit, as higher power outputs might be needed to counteract sub-optimal power delivery of the prosthesis. Therefore, the purpose of this study is to determine how incremental adjustments in prosthetic ankle power affect the metabolic cost of walking.

METHODS

Two males with transtibial amputation (ages 59, 24 yrs; BMI 28.9, 26.9 kg/m^2) were fitted with the BiOM T2 powered ankle prosthesis (BiOM, Inc. Bedford, MA) by a certified prosthetist. Subjects walked on a treadmill while the power supplied to the prosthesis was varied. Metabolic costs were measured using a portable gas analyzer (K4b^2, Cosmed, Rome, Italy). Treadmill speed was determined by subject leg length and remained consistent across conditions.

Each participant was given 10 minutes to accommodate to treadmill walking prior to testing. Subjects were tested at five ankle power setting conditions in random order: prosthetist-chosen (PC), 0%, 25%, 50%, 75% and 100% power. Participants were given five minutes to acclimate to each power setting, after which a 3-minute sample of expired air was acquired during steady-state oxygen consumption.

In order to determine if changes in metabolic costs were a result of a true metabolic change rather than normal variability, the minimal detectable change (MDC) value for metabolic cost of transport (COT) was determined. This was acquired by collecting steady-state oxygen consumption data on nine healthy subjects (age 23 ± 3 years, 56% male) during treadmill walking. Oxygen consumption was collected for three bouts of walking interrupted by three bouts of seated rest to obtain within-session variability of COT. Testing was performed on two separate days to determine between-session variability. Intraclass correlation statistics were performed on COT within a session and on the average COT between days. The MDC was calculated using the intraclass correlation coefficient [5] and compared to the changes exhibited in the subjects with amputation.

RESULTS AND DISCUSSION

The within-session MDC value determined for cost of transport was 0.016 J/N.m (Table 1). The between-day ICC was 0.878, and the MDC was 0.0543 J/Nm.

Table 1. Reliability of Cost of Transport (COT) Values for COT are given as mean (standard deviation) across nine healthy subjects for each of three bouts of treadmill walking over two days.

	COT (J/Nm)			ICC	MDC
	Bout 1	**Bout 2**	**Bout 3**		
Day 1	0.350 (0.077)	0.347 (0.063)	0.331 (0.065)	0.991	0.017
Day 2	0.346 (0.046)	0.350 (0.047)	0.349 (0.050)	0.987	0.015

For subjects with amputation, the COT tended to decrease as ankle power increased (Fig. 1). There were no measurable differences in COT in comparison to 0% power for S01, as this was measured on a separate day. COT was measurably diminished at 75% and 100% power for S01, whereas no detectable differences in COT were exhibited in the lower power levels or between 100% and higher power levels. The COT difference between PC (57%) power and 0% power was -0.013 J/N.m, falling below the between-day MDC value.

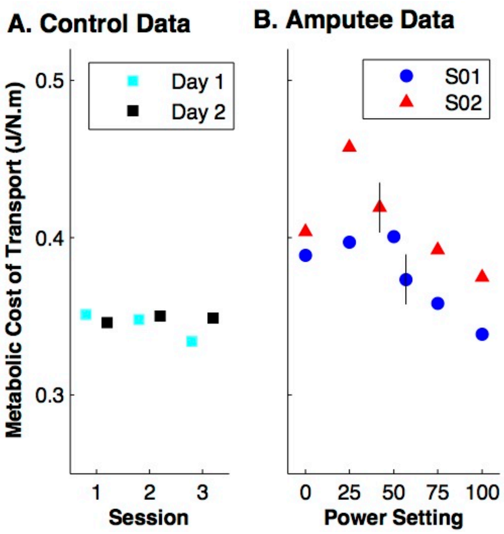

Figure 1: (A) Average COT for healthy subjects over two days over three sessions of walking and (B) COT during three minutes of steady state walking for two subjects with a solid line representing ± MDC (0.016 J/Nm) on PC power.

Subject S02 demonstrated measurable changes in COT between all power settings except for 75% to 0% power. COT was higher for PC (42%) power when compared to 0% power, and for 25% compared to 0% power (0.027 J/N.m and 0.0650 J/N.m respectively). All other pairings demonstrated measureable decreases in COT (Table 2).

For both subjects, increasing the power supplied by the prosthetic beyond PC power yielded decreases in cost of transport greater than the MDC (Table 1). Prosthetist-selected power settings were chosen in an effort to match the ankle work done by the intact limb. These data suggest that higher ankle work of the prosthesis may further reduce the metabolic cost of walking. It is possible that the power output of the prosthesis is not only compensating for the loss of plantarflexor power, but also reducing muscular compensations at the hip flexors of the residual limb [6]. Additionally, accommodating for any inefficiencies in power delivery of the device may lead to the necessity of power increases greater than that of the intact ankle. This inefficiency would lead to the dissipation of energy needed to aid powered ground push-off, thereby requiring increased power supply.

CONCLUSIONS

Increased power delivered by the ankle prosthesis was sufficient to reduce COT by measurable amounts. Future directions for this work include an examination of these parameters with a larger sample size. Characterizing the effects of the timing of power delivery on metabolic costs as well as changes in muscular activity will further clarify the mechanisms of these metabolic cost savings.

REFERENCES

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Table 2. Cost of transport (J/N.m) for two subjects across power settings (0-100%) and at the prosthetist-chosen power (PC). * = data taken on a separate day.

Subject	0%	25%	PC = 42%	50%	PC = 57%	75%	100%
S01	0.389*	0.397		0.401	0.376	0.358	0.338*
S02	0.392	0.457	0.419			0.392	0.375