INFLUENCE OF A FIXED ANKLE ON JOINT MECHANICS AND METABOLIC COST OF WALKING

Clinton J. Wutzke[1], Gregory S. Sawicki[1,2] and Michael D. Lewek[1]

[1]University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[2]North Carolina State University, Raleigh, NC, USA
email: cwutzke@med.unc.edu

INTRODUCTION

Inability to control the ankle muscles can contribute to gait deficits in people post-stroke [1]. Specifically, reduced power generation from the plantarflexors may result in compensatory movement strategies. These strategies may increase reliance on less efficient proximal muscles (e.g. hip) or the non-paretic limb to achieve a functional walking velocity [2]. Such compensations are thought to require greater metabolic energy expenditure and may contribute to reductions in walking endurance [1, 3].

The purpose of this study was to determine the effect of walking with reduced ankle power generation on metabolic cost and the redistribution of mechanical power generation in unimpaired subjects. To model reduced ankle plantarflexion generation, we had subjects walk with a unilaterally fixed ankle. We hypothesized that fixed ankle walking would elicit greater hip mechanical power generation in the braced (i.e. ipsilateral) leg, thereby increasing the net metabolic power demands of the task.

METHODS

All participants read, understood and signed an IRB approved consent form. Six unimpaired adults (5F, 1M, $\bar{x}$ age 23.3 $\pm$ 1.4 years; $\bar{x}$ mass 63.1 $\pm$ 5.9 kg) completed two treadmill walking conditions at 1.2 m/s (2.7 mph). Subjects wore a lockable ankle brace (Ballert International, LLC, FL; mass = 1.35 kg) on the dominant limb during both conditions. In one condition, subjects walked on the treadmill with the ankle locked in a neutral position (FIXED ankle) while in the other condition subjects walked with the brace unlocked (FREE ankle). Subjects walked for 4 minutes in each condition to achieve 'steady state' prior to a single 30 second collection of kinematic and kinetic data. A minimum break of 4 minutes was provided between conditions.

A motion capture system (VICON/PEAK, Denver, CO) was used to record three dimensional lower extremity kinematics (120 Hz) and an instrumented split-belt treadmill (Bertec Corp., Columbus OH) recorded ground reaction forces generated by each limb (1080 Hz). Peak positive mechanical power (normalized to body mass, W/kg) at the ankle and hip were calculated using inverse dynamics with Visual 3D software (C-Motion, Germantown, MD). Peak anteriorly-directed ground reaction forces were measured for each step and averaged for each condition. Finally, indirect calorimetry (OxyCon, Yorba Linda, CA) was used to determine mass specific net metabolic power [4].

Non parametric statistics (Wilcoxon sign rank tests) were used to identify differences between limbs and conditions (α=0.05).

RESULTS AND DISCUSSION

The braced limb exhibited a reduced peak ankle plantarflexion angle during the FIXED condition compared to the FREE condition (within limb change: p=0.028). Likewise, we observed a between limb change during FIXED ankle walking, with reduced plantarflexion observed in the braced ankle compared to the non-braced ankle (between limbs comparison: p=0.028). These results confirm that the brace restricted ankle movement during the FIXED ankle walking condition.

As anticipated, this reduction in ankle angle contributed to a reduction in peak ankle power during FIXED walking compared to FREE walking (p=0.028) and the non-braced limb (p=0.046) during FIXED walking.

Mass specific net metabolic power did not change between conditions (p=0.173; FREE ankle 3.59 ± 0.39 W/kg, FIXED ankle 3.79 ± 0.47 W/kg) (Figure 1).

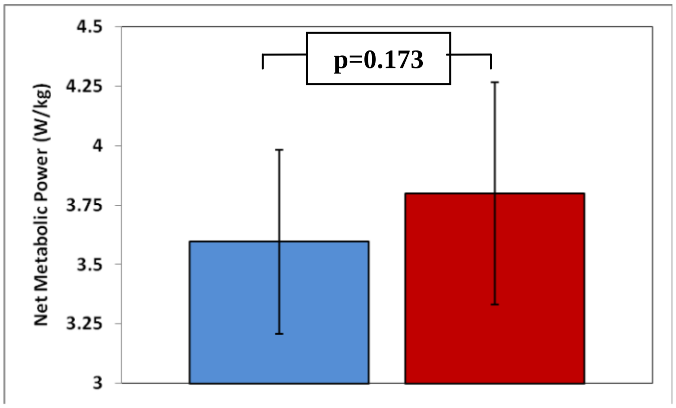

Figure 1: Mass specific net metabolic power during FREE (left) and FIXED (right) ankle walking conditions.

Peak hip power was significantly greater in the braced limb during FIXED ankle walking compared to FREE ankle walking (p=0.046) (Table 1).

The peak anteriorly directed ground reaction force of the braced limb did not significantly differ between FIXED and FREE ankle walking conditions (p=0.173). Peak anteriorly directed ground reaction force was significantly greater however in the non-braced limb compared to the braced limb during the FIXED ankle condition (non-braced limb 118.51 ± 17.06N, braced limb 95.24 ± 7.93N; p=0.046).

CONCLUSIONS

As hypothesized, subjects redistributed mechanical power production within the braced limb in order to maintain walking velocity in the FIXED ankle condition. Peak power output from the hip was increased to compensate for reduced peak ankle power.

Contrary to our expectations, the marked trade-off between peak ankle and peak hip mechanical power generation within the braced limb during FIXED ankle walking did not result in significantly elevated net metabolic power. Although we find evidence of redistribution of lower extremity power generation from the relatively efficient ankle muscles to the less efficient hip muscles in the braced limb during FIXED walking, it does not seem to significantly impact the overall metabolic demands of the task. Further mechanical analysis is necessary to further resolve this issue.

REFERENCES

1. Kesar, TM, et al., *Physical Therapy*, **90(1),** 55-66, 2010
2. Bowden MG, et al, *Stroke*, **37**, 872-876, 2006.
3. Olney SJ, et al, *Gait & Posture*, **4,** 136-148, 1996.
4. Brockway JM. *Hum Nutr Clin Nutr*, **41**:463–471,1987.

Table 1: Lower extremity ankle and hip kinematic and kinetic measures during free ankle (FREE) and fixed ankle (FIXED) walking conditions.

	FREE Ankle		FIXED Ankle	
	Non-Braced Mean ± SD	Braced Mean ± SD	Non-Braced Mean ± SD	Braced Mean ± SD
Peak Ankle Plantarflexion (deg)	19.92 ± 2.86	9.12 ± 2.96	19.52 ± 3.47	0.44 ± 3.25*†
Peak Ankle Excursion (deg)	27.80 ± 4.56	26.00 ± 3.17	27.44 ± 5.18	13.64 ± 3.75*†
Peak Ankle Power (W/kg)	3.04 ± 0.55	2.84 ± 0.20	2.96 ± 0.61	2.02 ± 0.47*†
Peak Hip Power (W/kg)	0.86 ± 0.24	0.93 ± 0.18	0.89 ± 0.22	1.00 ± 0.15*

* = p < 0.05 compared to free ankle walking condition.
† = p < 0.05 between limbs in fixed ankle walking condition.