The Motor in the Foot: Changes in Shod Foot Energetics with Increasing Walking Velocity

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Summary

In this study participants walked at increasing velocities while shod in order to measure joint work at the ankle, midtarsal, and metatarsophalangeal (MTP) joints. Results showed that the MTP joint acted as a mechanical damper, while ankle and midtarsal joints acted as mechanical motors, with these roles intensifying at higher velocities. This suggests that passive energy storage/return mechanisms, both biological and from external devices, play a diminished role at higher walking velocities, which require more active power generation.

Introduction

Foot and ankle structures play a pivotal role in the energetics of walking and in modulating gait velocity. Research on barefoot ankle-foot mechanics at varying speeds suggests that higher velocities increase the energetic demand of the foot and change the energetic roles of foot joints. However, supportive footwear constrains foot motion, thus likely altering the foot's response to changing velocity demands. Therefore, this study aimed to characterize typical shod ankle-foot joint energetics at a wide range of walking velocities. With increasing velocities, we hypothesized increased ankle, midtarsal, and MTP positive work (H1), decreased ankle negative work (H2), and increased midtarsal and MTP negative work (H3).

Methods

Both lower extremities including a three-segment foot were tracked as 18 participants (28.61±5.19 yrs, 76.73±16.87 kg, 1.71±0.09 m) walked at four height-normalized velocities ((0.4, 0.6, 0.8, 1.0 stat/sec) in random order while kinematic (200Hz) and kinetic (1000 Hz) data were collected. A custom real-time feedback program monitored walking velocity. Three trials for each foot were collected for each condition.

Forces were assigned to each foot segment based on the COP cross method [1]. Inverse dynamics were used to calculate joint power, which was integrated to extract positive and negative work. Work metrics were compared among velocities using repeated measures ANOVAs with Holm pairwise post-hoc tests.

Results and Discussion

The three ankle and foot joints studied exhibited distinct energetic behaviors as walking velocity increased (Table 1). The MTP joint functioned primarily as a mechanical damper, showing significant increases in negative work with only modest increases in positive work. In contrast, both ankle and midtarsal joints functioned predominantly as mechanical motors, with this role becoming more pronounced at higher velocities. The midtarsal joint generated substantial positive work while it had virtually no negative work, regardless of velocity. The ankle demonstrated significant increases in both positive and smaller, but still significant increases in negative work. When compared with previous research on barefoot walking [2], wearing supportive footwear appeared to attenuate both positive and negative work across all velocities. As velocity increased, the shift toward more motor-like behavior at the ankle and midfoot suggests a diminished role for passive energy storage/return mechanisms. While many passive assistive devices effectively replicate slower gait mechanics, their effectiveness may decrease at higher speeds that require active power generation.

Conclusions

These results emphasize 1) the increasing energetic demand of the ankle and foot with increasing velocities, and 2) velocity and footwear's impact on these roles. As velocity increased, the MTP increased its damper role while the ankle and midfoot became less spring-like and more motor-like.

Acknowledgments

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References

[1] Bruening et al. (2018). *Gait & Posture*, **62**: 111-116
[2] Eerdekens et al. (2022). *Gait & Posture,* **68**: 375-381

Table 1: Mean joint work during stance (±SD) in J/kg. Pairwise comparison results: [A]difference from 0.4stat/sec, [B]difference from 0.6 stat/sec, [C]difference from 0.8 stat/sec, [D]difference from 1.0stat/sec

	0.4 stat/sec	0.6 stat/sec	0.8 stat/sec	1.0 stat/sec	p-value
MTP Negative Work	-0.06 ± 0.02^{BCD}	-0.08 ± 0.02^{ACD}	-.09 ± 0.02^{ABD}	-0.12 ± 0.03^{ABC}	<0.001
MTP Positive Work	0.01 ± 0.00^{D}	0.01 ± 0.00^{D}	0.01 ± 0.00^{D}	0.01 ± 0.00^{ABC}	< 0.001
Midtarsal Negative Work	-0.01 ± 0.02	-0.01 ± 0.00	-0.01 ± 0.01	-0.01 ± 0.01	0.072
Midtarsal Positive Work	0.05 ± 0.02^{CD}	0.05 ± 0.02^{CD}	0.06 ± 0.02^{ABD}	0.07 ± 0.03^{ABC}	< 0.001
Ankle Negative Work	-0.18 ± 0.04^{D}	-0.19 ± 0.05^{D}	-0.18 ± 0.04^{D}	-0.15 ± 0.04^{ABC}	< 0.001
Ankle Positive Work	0.14 ± 0.04^{BCD}	0.17 ± 0.03^{ACD}	0.21 ± 0.05^{ABD}	0.27 ± 0.07^{ABC}	< 0.001