Metatarsophalangeal joint kinematics and muscle activations during transition walking between level and uphill

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Summary

This study examines the kinematics and muscle activations of the metatarsophalangeal (MTP) joint during transition walking from level to uphill (L-UH) and uphill to level (UH-L) walking. The findings reveal variations in muscle activation depending on the terrain, providing insights for prosthesis design to support transition walking including MTP joint.

Introduction

Prosthetic users navigate different walking conditions in their daily lives, including level surfaces, uphill, downhill, and transitions between different terrains. Individuals are required to coordinate lower limb muscle activities [1] to modulate lower limb joint angles [2] according to varying walking environments. The transition walking between level surface and uphill exhibits higher fall risk than level walking [3]. Although the MTP joint plays an important role during walking [4] and slopes [5], no studies have examined the MTP joint in such transitions, particularly with regard to its kinematics and associated muscle activations. The purpose of this study is to investigate the kinematics and muscle activation of the MTP joint during transition walking from level to uphill (L-UH) and uphill to level (UH-L).

Methods

Sixteen healthy males without lower extremity injuries (age: 22.9 ± 3.5, weight: 67.4 ± 10.7 kg, height: 173.6 ± 5.6 cm) walked on the flat-ground, uphill, and their transitions at a preferred speed. The max dorsiflexion angle of the MTP joint and the integrated EMG of flexor hallucis longus (FHL), extensor digitorum longus (EDL) during loading response, midstance, propulsive, and swing phase of a gait cycle were compared among level, uphill, UH-L, and L-UH, walking using the Kruskal Wallis and Mann-Whitney U test at a significance level of 0.05.

Results and Discussion

The EDL activation in UH-L was greater than that in L-UH during midstance ($P < 0.01$, Figure 1a). The preceding surface in UH-L is upward-directed in UH-L, whereas it is forward-directed in L-UH. Maintaining balance on an upward-directed surface requires greater stabilization effort, and EDL plays an important role in this process [6].

However, both EDL and FHL activation in UH-L were lower ($P = 0.01$ and $P = 0.05$, respectively, Figure 1c,d) than that in L-UH during propulsive phase. The upcoming surface in UH-L is forward-directed, whereas it is upward-directed in L-UH. The EDL and FHL require greater effort to drive the body forward against an upward-directed surface than against a forward-directed surface, playing crucial roles in this propulsion as MTP agonist and antagonist muscles [6].

No significant differences ($P > 0.05$) were found in the maximum MTP dorsiflexion angle in every phase. Additional specification with respect to dorsiflexion angle for the prosthesis including MTP joint were not required during transition walking between level and uphill, provided that the prosthesis was optimized to perform on level ground.

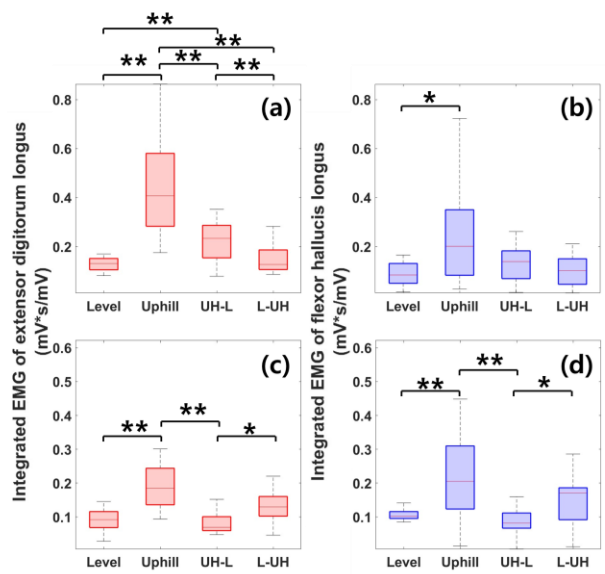

Figure 1 Representative boxplots of integrated EMG: (a) extensor digitorum longus during midstance, (b) flexor hallucis longus during midstance, (c) extensor digitorum longus during the propulsive phase, and (d) flexor hallucis longus during the propulsive phase (*$p < 0.05$, **$p < 0.01$)

Conclusions

This study suggests that proper control adjustments according to walking terrain are required when controlling the prosthesis during transition walking between level and uphill.

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