EMG-Based Insights into Residual Limb Muscle Function in Transtibial Amputees

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Summary

This study investigated the activation patterns of residual limb muscles in transtibial amputees (TTAs) to inform prosthetic control strategies. Using electromyography (EMG) activation of Tibialis Anterior (TA), Peroneus Longus (PL), Gastrocnemius Lateralis (GL), and Gastrocnemius Medialis (GM) were assessed during dorsiflexion, plantarflexion, and eversion at varying intensities. Results show variability in activation patterns across participants. TA exhibited dominant activation during dorsiflexion, while PL showed notable co-contraction. Conversely, during eversion, TA had atypically high co-contraction. PL displayed unexpected activity during plantarflexion. TA and PL activation patterns were inconsistent with those seen in non-amputees, likely due to cortical reorganization post-amputation. In contrast, GM and GL maintained their functional specificity post-amputation, showing no significant deviation in activation patterns compared to their expected roles. These findings suggest that prosthetic control systems should account for altered activation patterns and individual variability to optimize functional outcomes.

Introduction

The growing field of lower limb prosthetics focuses on EMG-based intuitive control. However, post-amputation changes in muscle structure and function, such as altered motor unit recruitment and co-contraction, challenge selective muscle activation. This study investigates residual muscles' activation patterns in TTAs and the implications for personalized prosthetic control.

Methods

Nine unilateral TTAs participated. EMG data were collected using wireless surface sensors (Trigno™, Delsys Inc., USA), with electrode placement confirmed via ultrasound. Tibialis Anterior (TA), Peroneus Longus (PL), Gastrocnemius Lateralis (GL), and Gastrocnemius Medialis (GM) of the residual limb were assessed. Participants performed seated muscle contractions mimicking dorsiflexion, plantarflexion, and eversion at their perceived 25%, 50%, 75%, and 100% effort of a maximum voluntary contraction (MVC). Each task lasted 2-3 seconds, with 10-second rest intervals, repeated twice. Root Mean Square (RMS) amplitude of submaximal trials was normalized to MVC. The co-contraction index (CCI) of non-primary muscles was calculated.

Results and Discussion

EMG analysis showed significant effects of muscle and activity on RMS amplitudes ($p<0.001$, Figure 1), with PL and TA exhibiting greater activation than GL and GM ($p<0.0001$) and plantarflexion produced the highest RMS amplitudes ($p<0.0001$). RMS amplitude also increased significantly with contraction intensity ($p<0.0001$). Substantial variability in muscle activation patterns was observed among participants. During dorsiflexion, TA was the most active muscle, reflecting its primary role, but PL exhibited high co-contraction (median CCI: 92.1%, IQR: 76.6–100.1). TA also showed high co-contraction during eversion (median CCI: 99.4%, IQR: 68.8–113.1), suggesting challenges in isolating PL, which was expected to dominate eversion. PL activation was consistent across all movements, with the highest CCI during plantarflexion (median: 118.2%, IQR: 100.8–133.1), with activation levels exceeding those of GM and GL, a pattern differing from non-amputees [1]. The synergy between TA and PL may, in part, be due to cortical reorganization post-amputation, redistributing motor control over residual muscles to compensate for sensory and biomechanical deficits. GL and GM were primarily activated during plantarflexion and exhibited low co-contraction during dorsiflexion (GL: median CCI: 44.7%, IQR: 27.3–64.4; GM: 27.2%, IQR: 15.4–38.6). This suggests these muscles largely retain their functional specificity despite amputation.

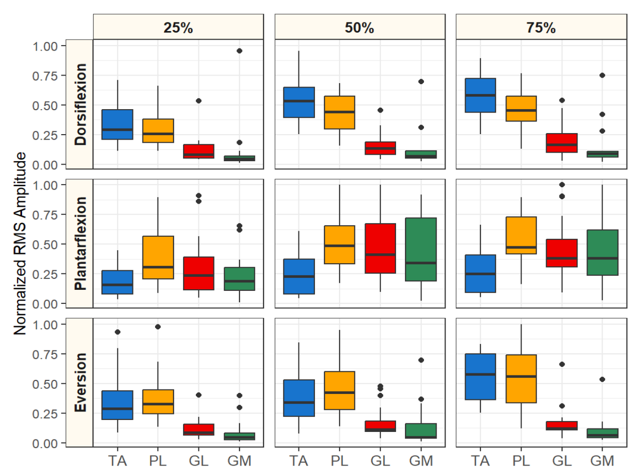

Figure 1: Normalized RMS amplitude for four residual muscles.

Conclusions

The study provides valuable insights into neuromuscular adaptations in TTAs, offering pathways for improving prosthetic performance. The potential of targeted training to enhance performance is unknown.

References

[1] Mendez-Rebolledo et al. (2021) *PLoS ONE* **16**(4): e0250159