Nonlinear Analysis of Postural Stability in Transfemoral Prosthesis Users: Insights from Approximate and Sample Entropy

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Summary

This study examines how visual input and stance width affect postural stability in transfemoral prosthesis users using Approximate Entropy (ApEn) and Sample Entropy (SampEn). Seven unilateral transfemoral amputees were tested under four standing conditions: eyes-open wide (EOW), eyes-open narrow (EON), eyes-closed wide (ECW), and eyes-closed narrow (ECN). Results showed increased entropy in ECW, especially in the mediolateral (ML) direction, indicating greater instability. Visual input removal combined with a wide stance amplified postural fluctuations. While both metrics showed similar patterns, SampEn's higher reliability supports its use in short-duration assessments. These findings highlight the influence of vision and stance on balance and support nonlinear metrics for evaluating postural stability.

Introduction

Transfemoral prosthesis users face postural challenges due to limited proprioceptive feedback, requiring compensatory strategies. Conventional COP measures describe balance but fail to capture postural control complexity. Nonlinear analysis methods such as Approximate Entropy (ApEn) and Sample Entropy (SampEn) provide a more detailed evaluation by quantifying signal complexity and irregularity. This study examines how visual input and stance width affect balance in transfemoral prosthesis users and compares the utility and reliability of ApEn and SampEn.

Methods

Seven unilateral transfemoral amputees (mean age: 57.3 ± 13.7 years, height: 172.4 ± 4.9 cm, weight: 73.7 ± 10.4 kg) participated in this study. Each participant performed four standing trials: eyes-open wide stance (EOW), eyes-open narrow stance (EON), eyes-closed wide stance (ECW), and eyes-closed narrow stance (ECN). Each trial lasted 20 seconds, during which center of pressure (COP) data were collected at 100 Hz using a Kistler force plate. ApEn and SampEn were calculated using MATLAB. A two-way repeated measures ANOVA assessed stance and vision effects, followed by post-hoc tests.

Results and Discussion

Although SampEn is generally recommended for long time-series data, it showed strong consistency with ApEn in this study, supporting its application for shorter balance assessments. SampEn showed greater reliability, suggesting it as a preferred postural stability metric. [2].

Increased entropy under the ECW condition, especially in the mediolateral direction, indicates that combining visual input removal with a wide stance challenges balance control. This was supported by significant stance (ApEn_Y: p = 0.004, SampEn_Y: p = 0.003) and interaction effects (ApEn_Y: p = 0.029, SampEn_Y: p = 0.027). Results highlight the need for stance-specific proprioceptive training.

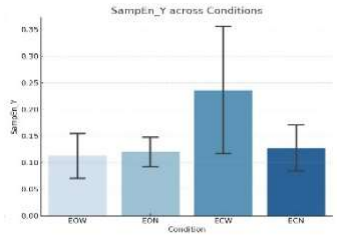

Figure 1: Changes in Nonlinear Postural Stability Measures (SampEn) Across Different Stance Conditions.

Conclusions

This study demonstrates that nonlinear center of pressure (COP) analysis can offer meaningful insights into the postural control mechanisms of transfemoral prosthesis users. Notably, the ECW condition led to increased instability, particularly in the mediolateral (ML) direction, highlighting the importance of proprioceptive adaptation in maintaining balance. Although typically used for long data, SampEn aligned with ApEn, supporting short-trial use. These findings reinforce the need for tailored rehabilitation strategies focused on enhancing proprioceptive control.

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