

Biomechanical Characterization Before, During, and after Freezing of Gait Episodes in Parkinson's Disease

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Abstract

Introduction: Freezing of gait (FoG) is a disabling and episodic phenomenon in Parkinson's disease (PD), leading to falls, reduced mobility, and impaired quality of life (1). Although multiple studies have described FoG occurrence, little is known about biomechanical alterations immediately preceding and following freezing episodes (2). Recent advancements in wearable sensors have enabled the objective quantification of FoG using parameters such as the Freezing Ratio (3), but the dynamic transitions around freezing events remain poorly characterized.

Method: We analyzed a dataset comprising individuals with PD assessed during two home visits. Each participant was evaluated in Off-medication. During the assessments, participants wore a triaxial accelerometer (Ax3, Axivity) placed on the lower back sampling at 100 Hz. The protocol included multiple gait and turning tasks designed to provoke freezing, such as 4-meter walk, Timed Up & Go (single and dual-task), repeated turning tasks, and Hotspot walking trials through individualized freezing-prone environments. For the present analysis, episodes of continuous walking where freezing events were identified were segmented into three phases: Pre-FoG (2 seconds before onset), During FoG (identified by visual inspection and acceleration patterns), and Post-FoG (2 seconds after resolution). The FoG Ratio, as described by Mancini et al. (3), was calculated based on the power spectral density of the anteroposterior (AP) accelerations, comparing high-frequency (3–8 Hz) to low-frequency (0.5–3 Hz) components.

Results: The observed reduction in acceleration amplitude prior to freezing suggests an early impairment in postural adjustments and gait rhythm preceding FoG onset, possibly reflecting deficits in motor planning or anticipatory control. The elevated AP FoG Ratio during freezing confirms its utility as a specific marker of the freezing state, consistent with prior literature validating its clinical relevance (3). The post-freezing recovery phase exhibited a rapid normalization of biomechanical parameters, highlighting the transient and abrupt nature of FoG events. These biomechanical signatu-

res may reflect the interplay between supraspinal gait control mechanisms and the impaired dynamic coordination that characterizes FoG.

Discussion: Our study provides novel evidence of biomechanical alterations not only during but immediately before and after FoG episodes. The distinct pre-FoG signature observed may serve as a critical window for predictive algorithms and real-time interventions aimed at preventing freezing events. The use of wearable sensors and spectral analysis of accelerometry data offers a feasible and ecologically valid approach for continuous FoG monitoring in natural environments.

Conclusions: Repeated measures ANOVA revealed significant differences across the three phases in all acceleration axes (AP, ML, and VT). Post-hoc Bonferroni comparisons demonstrated that pre-FoG phases were characterized by significantly reduced acceleration amplitudes compared to post-FoG periods across all axes ($p < 0.05$). Notably, for the AP axis, the During FoG phase exhibited significantly different FoG Ratio values compared to both Pre- and Post-FoG phases ($p < 0.05$), indicating increased high-frequency oscillations corresponding to the characteristic trembling observed during freezing episodes. These findings support the FoG Ratio's sensitivity in capturing freezing severity and transition dynamics.

References

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