Frequency-Specific Respiratory–Postural Coupling During Standing in Parkinson's Disease

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Objective: To quantify frequency-domain directional coupling between respiratory, cardiovascular, musculoskeletal, and postural systems in healthy controls (HC) and Parkinson's disease (PD) patients with and without orthostatic hypotension (OH) during standing.

Methods: We recorded electrocardiogram, continuous blood pressure, respiration, lower limb electromyography (EMG), and center of pressure (COP) signals from 19 PD patients and 10 age-matched HC during standing following a head-up tilt test. Seven PD patients exhibited OH (PD+OH), while twelve did not (PD−OH). Mediolateral (ML) and anteroposterior (AP) sway were computed. Fast and Adaptive Multivariate Empirical Mode Decomposition was used to extract aligned oscillatory components across signals. Representative center-of-pressure low-frequency (LF) and high-frequency (HF) modes were selected, and convergent cross mapping was applied to quantify bidirectional coupling.

Results: All groups exhibited bidirectional interactions among respiration, postural sway, muscle activity, and blood pressure. PD−OH patients showed significantly higher LF respiration→ML sway coupling compared to HC and PD+OH ($p<0.02$), indicating increased respiratory-driven postural perturbations. PD+OH patients demonstrated reduced LF EMG→ML sway coupling compared to HC and PD−OH ($p<0.01$), suggesting diminished effectiveness of lower limb muscles to maintain mediolateral balance. In addition, PD+OH exhibited increased LF AP sway→EMG and respiration→EMG coupling ($p<0.05$), consistent with compensatory activation of lower limb muscles in response to increased postural and respiratory perturbations. Moreover, respiration was found to predominantly influence postural sway and muscle activity in the LF band, while feedback from postural and muscular systems toward respiration was more prominent in the HF band, indicating distinct time-scale mechanisms of interaction that cannot be captured using conventional time-domain causality analysis alone.

Conclusion: Frequency-domain directional coupling analysis reveals distinct physiological patterns in Parkinson's disease with and without orthostatic hypotension. These findings demonstrate that multiscale interaction metrics can identify dysfunction not captured by conventional measures and may support improved assessment of fall risk and targeted interventions in Parkinson's disease.