Heart Rate Variability Is More Sensitive During Sleep Stage Transitions than within Individual Sleep Stages

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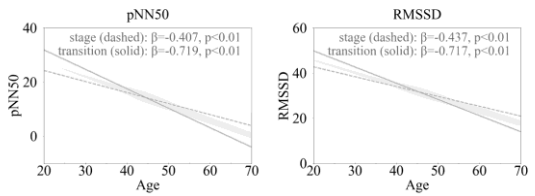
Aims: This study aimed to compare heart rate variability (HRV) changes between stable sleep stages and sleep stage transitions, and to evaluate whether transition segments provide greater sensitivity to age-related autonomic changes and obstructive sleep apnea (OSA)-related dysfunction.

Methods: We analyzed an open dataset from the Cleveland Family Study (CFS), a large-scale polysomnography database. Subjects were categorized into healthy sleepers (n=289) and OSA patients (n=181). ECG signals were segmented into 5-minute epochs for single-stage analysis. Sleep stage transition segments were defined as the 5-minute periods preceding transitions, based on evidence that ECG-derived autonomic changes precede EEG-defined transitions. Parasympathetic-related HRV indices, including high-frequency power (HF), root mean square of successive differences (RMSSD), and the percentage of successive R-R intervals differing by more than 50ms (pNN50), were extracted. Linear regression analysis was performed to evaluate age-related trends, and slope differences between stable sleep stages and transition segments were compared. Linear Mixed Model (LMM) was applied to evaluate the effects of age, OSA status, and their interaction (OSA x age).

Results: RMSSD and pNN50 significantly decreased with age in both groups ($p < 0.05$). Notably, healthy sleepers exhibited large absolute declines during sleep stage transitions than within stable sleep stages (RMSSD: 0.72 vs. 0.44; pNN50: 0.72 vs. 0.41). LMM analysis revealed that OSA status and their interaction (OSA x age) effects were significant only during transition segments, indicating enhanced sensitivity to pathological changes ($p < 0.01$).



Conclusions: HRV changes are more pronounced during sleep stage transitions than within stable sleep stages. These findings suggest that transition segments provide a more sensitive segment for detecting age-related autonomic decline and OSA-related dysfunction, highlighting their potential utility in sleep-related physiological assessment.