Deep Learning Analysis of Diving Reflex RR-Interval Dynamics: A Conv-LSTM Autoencoder Approach to Detect Sex-Based Autonomic Differences

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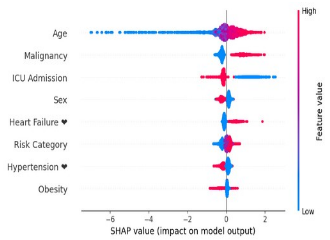
Background: The diving reflex induces rapid vagally mediated bradycardia, as a a protective mechanism enabling apnea through bradycardia, whose sex-specific temporal dynamics are incompletely understood. A data-driven approach could reveal autonomic signatures inaccessible to hand-crafted features.



SHAP values for mortality prediction

Aims: o train a Conv1D–Bidirectional LSTM autoencoder on female RR intervals and use its reconstruction error as a novelty score for detecting sex-specific autonomic divergence

Methods: We investigated gender and age-related differences in 44 healthy volunteers (17 men, 30.05+-13.30; 27 women, 24.62+-10.71 yrs). After a 5-min baseline, participants performed three cold-water facial immersion apneas, with HR monitored via Firstbeat®.The autoencoder was trained on 256-sample RR segments from 620 healthy women (PhysioNet Autonomic Aging, ages 18–59). Mean reconstruction (MSE) was computed per subject. Group differences were tested with Bonferroni-corrected Mann–Whitney U (alpha = 0.05). Latent vectors were projected via PCA.

Results: Reconstruction error was equivalent between sexes at baseline and rest ($p > 0.05$). During all three apneas and both inter-apnea recoveries, men showed significantly higher MSE ($p < 0.05$), with an apnea-induced increment ~18× larger than in women. Physically active subjects had lower error than sedentary counterparts in both sexes ($p = 0.018$), most markedly during apnea. Latent-space PCA showed sex-related offset that widened from baseline to apnea and persisted during recovery in men.

Conclusions: The autoencoder cleanly separates male and female autonomic dynamics during the diving reflex, confirming a reflex-specific rather than tonic divergence. Physical fitness attenuates this sex gap. These findings extend classical results, demonstrating that deep learning autoencoders detect sex-specific physiological signatures beyond parametric approaches.