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Making Sense of Heart Rate Variability: Identifying Meaningful Metrics for Stress and Pain Prediction

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Abstract:

Lower back pain (LBP) remains an increasingly prevalent and disabling condition worldwide, with most cases classified as non-specific and characterised by persistent or fluctuating symptoms that impair individuals' quality of life and productivity. Emerging studies suggest that LBP is often a chronic condition characterised by fluctuating symptoms rather than a static state. Despite extensive research, evidence on risk factors on LBP flares is weak (Taylor et al. (2014)) and current approaches fail to integrate real-time physical monitoring. This limits our ability to capture the dynamic role of stress as a modifier of acute pain episodes.

However, stress itself is difficult to measure directly from our everyday life. Instead we can infer the impact of stress by observing how it changes physiological processes such as heart rate dynamics. Heart Rate Variability (HRV) - the natural changes in time between successive heartbeats over time - offers a non-invasive method to quantify these effects, making it a promising tool for understanding how stress contributes to pain flares. offers a non-invasive method for quantifying these effects, making it a promising tool for understanding how stress contributes to pain flares. Although HRV is increasingly applied across medicine, physiology and exercise science, its use in pain research is limited. A further challenge is that more than 20 HRV metrics exist in literature (Shaffer and Ginsberg (2017)), many of which are mathematically interrelated. This creates uncertainty about which measures provide clinically meaningful insights, or those that are redundant or duplicative (when some are easier to obtain than others). Without resolving this, efforts to integrate HRV into pain prediction models risk being noisy and inconsistent.

Wearable devices provides a practical solution to integrate real-time physical monitoring and collecting data into daily life. Modern wearables, such as Garmin, can continuously capture HRV and related physiological signals in natural setting. This enables non-invasive tracking as people go about their everyday life.

To address this gap, we set out to build models that predict the onset and drivers of LBP flares using HRV features derived from wearable data. Specifically, we aim to identify which HRV metrics uniquely capture physiological stress, and which can be streamlined to improve interpretability and utility. Our approach combines HRV, stress, and sleep data collected from Garmin wearable devices worn by multiple participants. We examined the behaviour of HRV metrics across daily transitions to evaluate the stability and reliability under real-world conditions.

This work aims to provide both a methodological framework and practical tools by reducing the redundancy among HRV measures and demonstrating their application in predicting pain-relevant stress states. These advances support researchers and clinicians in effectively leveraging wearable HRV measurements, with the ultimate goal of enabling personalised, real-time monitoring to better anticipate and manage LBP flares.

Keywords: *Heart Rate Variability, Lower Back Pain, Wearable Devices, Feature Selection, Predictive Modelling*

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