Development of a probabilistic EMG-Based Risk Metric for Musculoskeletal Fatigue Assessment

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Summary

Musculoskeletal disorders are a leading cause of occupational injuries, often linked to cumulative muscle fatigue [1 [2]. Although tools like REBA quantify risk from kinematic data, a comprehensive metric incorporating surface electromyography (sEMG) remains undeveloped. This study introduces a novel EMG Risk Index (ERI), implementing time and frequency domain features to provide a quantitative scale for muscular fatigue and risk evaluation. The ERI incorporates Root Mean Square (RMS) and Median Frequency (MDF) metrics and proposes a fatigue probability model using a sigmoid transformation, making it a scalable tool for ergonomic assessment.

Introduction

Work-related musculoskeletal disorders are heavily influenced by sustained muscle activity and fatigue. While methods such as REBA effectively assess postural risks, they do not account for muscular fatigue. sEMG offers potential for fatigue monitoring, capturing the muscle's electrical activity over time [2]. Current risk-assessment approaches often lack a unifying metric for real-time fatigue evaluation across muscles. This study proposes the EMG Risk Index (ERI) to address this gap, incorporating temporal and frequency characteristics for a holistic fatigue assessment.

Methods

The ERI quantifies muscle fatigue by integrating RMS (amplitude of muscle activation), MDF (spectral shifts linked to motor unit recruitment), and task duration into a unified fatigue index. RMS and MDF are normalized to baseline values and combined with a time-dependent weight that amplifies as task duration increases, reflecting prolonged activity's influence on fatigue (1). This dynamic fatigue probability is modeled using a sigmoid function, capturing both immediate and cumulative fatigue effects (2).

$$\mathrm{FI}(t) = \beta_1 \cdot \left(\frac{\mathrm{RMS}(t) - \mathrm{RMS}(0)}{\mathrm{RMS}(0)}\right) + \beta_2 \cdot \left(\frac{\mathrm{MDF}(t) - \mathrm{MDF}(0)}{\mathrm{MDF}(0)}\right) + \beta_3 \cdot T \quad (1)$$

$$P_{\mathrm{fatigue}}(t) = \frac{1}{1 + e^{-\mathrm{FI}(t)}} \quad (2)$$

with, β1, β2, and β3 as RMS, MDF, and cumulative time (T), weights respectively.

Framework was validated through experiments on two individuals performing repetitive arm movements targeting the biceps and triceps until subjective fatigue was reached. sEMG signals were recorded and normalized to each participant's Maximum Voluntary Contraction (MVC) using a rolling-window of 1s [2].

Results and Discussion

Analysis revealed that RMS and MDF synergistically assessed fatigue, with the time-dependent factor enhancing sensitivity to prolonged activity, **Figure 1**. The preliminary study shows the ERI effectively captures dynamic fatigue profiles counting for temporal-spectral slopes. Moreover, at low durations, T's influence is minimal, highlighting immediate muscular responses. As T increases, FI incorporates prolonged activity effects, aligning with physical fatigue manifestations. The probabilistic model ensures scalability for tasks of varying intensity, offering insights into real-time fatigue progression. This method advances beyond existing indices by integrating multiple EMG features, capturing both temporal and spectral fatigue dimensions. Future work will involve validation in workplace scenarios, benchmarking against established ergonomic tools.

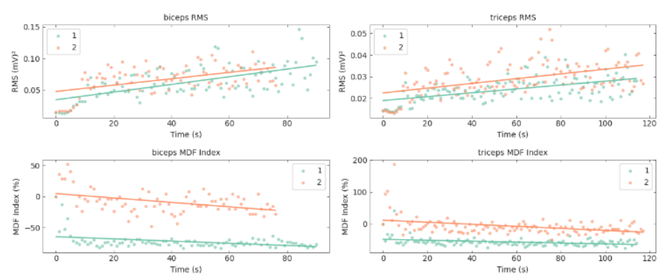

Figure 1: RMS and MDF fatigue trends for subject 1 across tests

Conclusions

The ERI provides a quantitative framework for assessing musculoskeletal fatigue, integrating RMS, MDF, and task duration in a unified metric. By incorporating temporal dynamics, the ERI offers a scalable and holistic approach for ergonomic risk evaluation, complementing existing kinematic methods like REBA. This tool has the potential to guide interventions aimed at reducing work-related musculoskeletal risks. While the framework shows promise, further research is required to refine the model and enhance its generalizability. The current validation involved a limited sample size and focused on specific muscle groups. Expanding the dataset to include diverse participants and tasks would allow for statistical inference and enable the optimization of weight coefficients for RMS, MDF, and time.

References

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