

Fatigue Detection During Wall-Sit Exercise Using Statistical Features of Chest ECG-Derived EMG

Chanki Park¹, Chul Huh¹, Hyung Ju Park¹

¹ Digital Biomedical Research Division, Digital Convergence Research Laboratory, Electronics and Telecommunications Research Institute (ETRI), Republic of Korea
chanki@etri.re.kr

Summary:

Muscle fatigue monitoring during isometric exercise can support safer training and rehabilitation, but conventional limb sEMG setups can be inconvenient in daily use. This work investigates four-class fatigue detection from the myoelectric component extracted from chest ECG during wall-sit exercise. Six healthy adults performed wall-sit until task failure, and the signal was segmented into non-overlapping 1 s windows labeled as rest, low fatigue, moderate fatigue, and high fatigue. Standard deviation, skewness, and kurtosis were used to train a bagging tree classifier. The proposed approach achieved an overall accuracy of 67.5% in 10-fold cross-validation and demonstrates that simple distribution-based features from chest ECG-derived EMG can support low-complexity fatigue sensing.

Keywords: muscle fatigue, wall-sit, chest ECG-derived EMG, statistical features, bagging tree

Background, Motivation and Objective

Muscle fatigue assessment is important in exercise coaching, rehabilitation, and wearable monitoring [1,2]. Surface EMG is widely used to characterize myoelectric manifestations of fatigue, and both amplitude-related and distributional signal properties change during sustained contraction [1-3]. Recent studies have also explored exercise fatigue analysis using ECG and EMG together [4]. In this work, we investigate whether a practical four-class fatigue model can be built from the EMG component extracted from a chest ECG measurement during wall-sit exercise. The objective is to distinguish rest, low fatigue, moderate fatigue, and high fatigue using a small number of features that are suitable for embedded or wearable implementation.

Description of the New Method or System

Six healthy adults performed wall-sit until failure while a chest ECG signal was recorded. To isolate the myoelectric component, the ECG was band-pass filtered between 100 and 500 Hz, and the resulting ECG-derived EMG was divided into non-overlapping 1 s segments. Rest data were labeled as the rest class. For each wall-sit trial, the initial 33% of the time-to-failure interval was labeled as low fatigue, the middle 33% as moderate fatigue, and the final 34% as high fatigue. The dataset comprised 1,958 labeled segments in total: 480 rest, 486 low fatigue, 486 moderate fatigue, and 506 high fatigue. Three statistical descriptors were extracted from each segment: standard deviation (STD), skewness, and

kurtosis. A bagging tree classifier [5] was trained to predict the four fatigue classes, and performance was evaluated by 10-fold cross-validation.

Results

Fig. 1 shows the temporal evolution of the statistical features during rest and wall-sit. As wall-sit progressed, STD increased gradually, indicating that the EMG amplitude and the level of muscle activation became larger as fatigue accumulated. In contrast, the magnitude of skewness decreased toward zero, which suggests a more symmetric signal distribution at higher fatigue levels. Kurtosis decreased from approximately 20-30 in the early stage to about 5 near task failure, implying a transition of EMG distribution from a super-Gaussian toward a more Gaussian [3]. These consistent trends confirm that the selected features capture both amplitude changes and distributional reshaping associated with sustained isometric exertion.

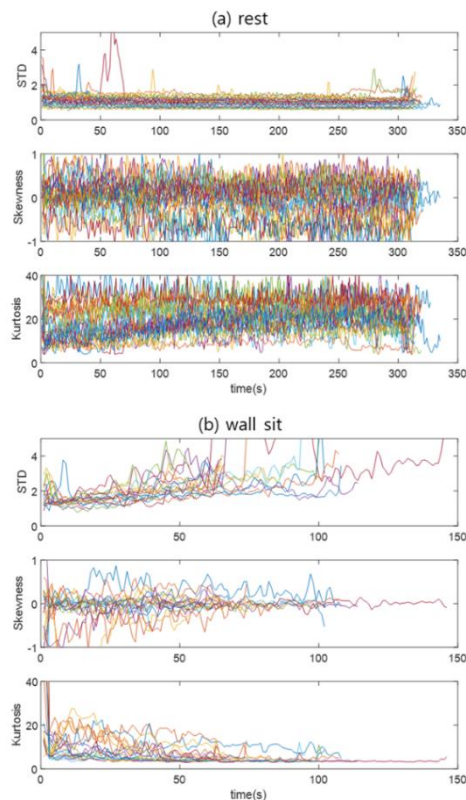


Fig. 1. Temporal variation of STD, skewness, and kurtosis for rest and wall-sit segments. (a): rest and (b): wall sit.

The fatigue classification performance is depicted in Table. 1. The proposed classifier achieved an overall accuracy of 67.5%. The rest class showed the highest recall at 80.6% (387/480), whereas low fatigue and moderate fatigue were more difficult to separate because their physiological characteristics partly overlapped. Most misclassifications occurred between adjacent fatigue stages, especially low versus moderate fatigue and moderate versus high fatigue, rather than between distant states. The high-fatigue class still reached a recall of 69.6% (352/506), which is encouraging for practical monitoring because the late stage is the most relevant for preventing performance collapse.

Overall, chest ECG-derived EMG features enabled meaningful fatigue-state discrimination. In future works, we plan to advance the fatigue

analysis based on multi-modal electrophysiological signals.

Tab. 1: Confusion matrix of four-class fatigue classification.

Actual Class	rest	low fatigue	moderate fatigue	high fatigue
rest	387	72	10	11
low fatigue	70	288	78	50
moderate fatigue	9	73	294	110
high fatigue	14	21	119	352
Predicted Class				

References

- [1] J. Sun, G. Liu, Y. Sun, K. Lin, Z. Zhou, J. Cai, Application of surface electromyography in exercise fatigue: a review, *Frontiers in Systems Neuroscience* 16, 893275 (2022); doi: 10.3389/fnsys.2022.893275.
- [2] M. Gazzoni, A. Botter, T.M. Vieira, Surface EMG and muscle fatigue: multi-channel approaches to the study of myoelectric manifestations of muscle fatigue, *Physiological Measurement* 38, R27-R60 (2017); doi: 10.1088/1361-6579/aa60b9.
- [3] K. Nazarpour, A.H. Al-Timemy, G. Bugmann, A. Jackson, A note on the probability distribution function of the surface electromyogram signal, *Brain Research Bulletin* 90, 88-91 (2013); doi: 10.1016/j.brainresbull.2012.09.012.
- [4] D. Mu, F. Li, L. Yu, C. Du, L. Ge, T. Sun, Study on exercise muscle fatigue based on sEMG and ECG data fusion and temporal convolutional network, *PLoS One* 17, e0276921 (2022); doi: 10.1371/journal.pone.0276921.
- [5] L. Breiman, Bagging predictors, *Machine Learning* 24, 123-140 (1996); doi: 10.1007/BF00058655.

ACKNOWLEDGEMENTS

This project was supported the Institute of Information & Communications Technology Planning & Evaluation (IITP) grant funded by the Korean government (MSIT-2022-0-00025).