

Surface EMG-Based Analysis of Neck and Shoulder Muscle Fatigue During Office Work Using MATLAB

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Abstract— Performing repetitive tasks at work puts a great deal of stress on the neck and shoulder complex, which often results in musculoskeletal disorder and decreased productivity. This research focuses on physiological processing of muscle fatigue in the Trapezius and Sternocleidomastoid (SCM) muscles by comparing the signal characteristics of a fresh (Normal) condition and a post exercise (Fatigue) condition. Surface electromyography (sEMG) signals were processed using standard algorithms to get Root Mean Square (RMS), Median Frequency (MDF) and Integrated EMG (IEMG). “The results demonstrated a clear compensatory fatigue response, with RMS and IEMG increasing significantly ($p < 0.05$) by +53.9% and +80.1%, respectively, reflecting elevated neural drive and neuromuscular cost.” Of note, MDF showed rising trend (+15.1%) instead of classical dropping and pointed out a compensatory increase in force-related motor unit recruitment to maintain task performance during dynamic movement. These results support the usefulness of sEMG as an important tool for identifying the shift from normal motor control to high effort strategies for compensation, and can provide a quantitative basis for designing ergonomic interventions to prevent chronic work-related musculoskeletal injuries.

Keywords— *Surface electromyography (sEMG), muscle fatigue, trapezius muscle, sternocleidomastoid muscle, median frequency (MDF), office ergonomics.*

I. INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) of neck and shoulder complex is a common occupational health problem, especially in office workers due to their extended sedentary time and repetitive work on the computer [5], [17]. Sustained static loading of the Trapezius and Sternocleidomastoid (SCM) muscles is a common occurrence which leads to localized muscle fatigue being a precursor to chronic pain, discomfort

and lower productivity at work [5], [6]. To quantify this physiological decline, Surface Electromyography (sEMG) is widely deemed as the gold standard that incorporates time domain features, such as Root Mean Square (RMS) and Integrated EMG (IEMG), along with frequency domain, such as Median Frequency (MDF) [15], [16]. Classically, muscle fatigue is defined by a “myoelectric manifestation of fatigue” pattern: a reduction in MDF (spectral compression) and an increase in signal amplitude (RMS) at the same time, which is a reflection of altered motor unit recruitment and a slowing conduction velocity [7]-[9].

Although the physiological mechanisms of fatigue have been well understood, much of the literature to date has been based on laboratory protocols that rely on controlled settings of high intensity isometric contraction and are largely devoid of ecological validity in dynamic office environments [10], [11]. There is still a critical need for task-relevant research for monitoring the progression of fatigue during simulated occupational activities which analyses the adaptations of the neuromuscular system in both the time and the frequency domains.

To obtain a high-fidelity signal, the BIOPAC MP36 data acquisition system is used in this study. This platform is known as being reliable in the recording of complex biopotentials in both the clinical and research environments. The versatility of the system has been shown in a wide range of biomedical applications that employ wearable diagnostics for preterm labor [19], AI-based bruxism classification [20], multi-posture EMG analysis during sleep [21] and sensing body imbalance in immersive environments [22]. Taking advantage of such

powerful instrumentation is necessary to pick up the subtle physiological changes associated with early-onset muscle fatigue.

Consequently, the main goal of this research work is to fill the existing gaps of the literature by analyzing the fatigue characteristics of the Trapezius muscle and the sternocleidomastoid muscle during simulated office tasks. By extracting and comparing meaningful sEMG parameters (RMS, IEMG, MDF) for the Normal (baseline) and Fatigued conditions, this research aims to identify the compensatory motor strategies. These insights will contribute to the development of targeted ergonomic intervention that aims to reduce the risk of WMSDs in the contemporary sedentary workplace.

II. LITERATURE REVIEW

Muscle fatigue is a big problem in occupational biomechanics particularly among office personnel and individuals engaged in repetitive work with their upper limbs. Studies show that continuing the same activity for a long period leads to tiredness that alters the activity and movement pattern of the muscles [1], [3], [5]. Most researchers consider surface electromyography (sEMG) to be the best method of measuring this fatigue. By considering time and frequency properties such as Median Frequency (MDF), Root Mean Square (RMS) and Integrated EMG (IEMG) it is possible to monitor physiological changes without being invasive [2], [16]. If we are looking in real time to sEMG data, the way that fatigue will generally appear would be a decrease in the MDF during fatigue since the muscle fibers conduct the signals at a slower rate. At the same time, the RMS amplitude tends to go up. This occurs because, the nervous system attempts to compensate by increasing the number of motor units in order to maintain a steady force level [15], [17]. While things like exercises, rest breaks and exoskeletons offer promise in helping with this [6], [7], [11], the tools we have right now aren't perfect. A large percentage of validation research occurs in controlled laboratories which is not necessarily applicable to the actual work conditions in the office [8], [10]. Recent literature also presents a gap on how we do our fatigue standardization. Current methods often do not consider different demographics, or how different people adapt to fatigue [4], [8]. To overcome this, recent studies recommended the combination of the two methods - sEMG and motion analysis and ML for more accurate detection [19], [22]. This demonstrates an obvious need for research that bridges the gap between the theory of biomechanics and the use of practical monitoring measures in the workplace.

III. MATERIALS AND METHODS

The procedures applied in this study are described in the following sections including participant recruitment, equipment preparation, experimental set-up, processing of the sEMG data, feature extraction and statistical analysis.

A. Participants

A total of 10 healthy people between the ages of 19 and 24 (5 males and 5 females) were part of this study. All the participants were full-time university students, who were right-handed and had no history of disorders affecting muscles, nerves, or the upper limb. Before they took part in the research, every Participant gave written confirmation that they approved following the Declaration of Helsinki. The university's research ethics committee allowed the protocol to be carried out as an experiment.

Similar groups were chosen for this research as had been done previously in such fatigue-related ergonomic studies, making the results reliable [3], [9], [17].

Table 1 Demographic Information of Participants

Parameter	Value
participants	10
Gender	5 Male, 5 Female
Age (years)	19–24
Mean age	21.3 ± 1.5
Health status	Physically fit, no upper limb disorders

B. Equipment and Data Acquisition

BIOPAC Systems Inc.'s MP36 was used to record the surface electromyography (sEMG) data. On the dominant side, both upper trapezius and sternocleidomastoid (SCM) belly muscles were each measured using following SENIAM guideline-compliant neck muscle surface electrodes. The investigators kept the distance between their electrodes at 2 cm. The sampling rate for all the recordings was picked as 2000 Hz. The laboratory temperature was controlled at 17°C when the data collection took place to guarantee that all conditions stayed the same.

Because it has already been proven effective and dependable, surface electromyography (sEMG) was selected to assess muscle fatigue and patterns of activity as shown in many ergonomic and biomechanical research [2], [15], [16].

C. Experimental Protocol

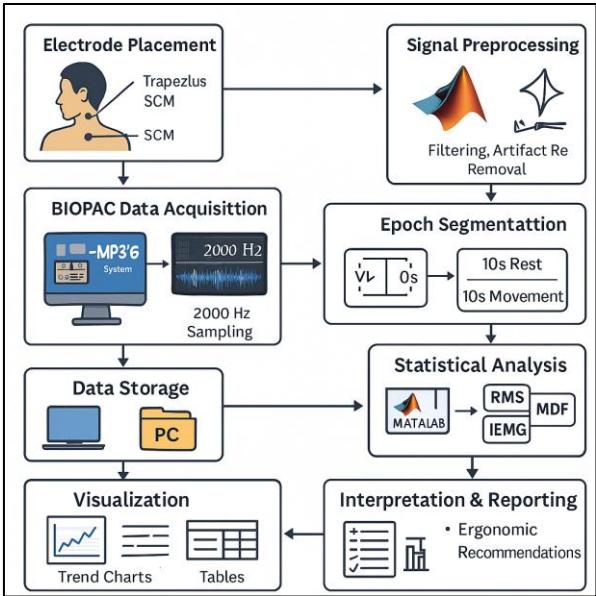


Figure 1 Block diagram illustrating the data acquisition and sEMG analysis workflow for muscle fatigue assessment

Every participant's baseline sEMG data were obtained before their muscles had fatigued. After that, the participants did a sequence of upper arm exercises for the right amount of time (10 minutes) to feel fatigued in their muscles. After the intense activity, post-fatigue sEMG measurements were recorded just like the previous one.

Using participants to complete many upper-limb movements and getting them fatigued in a planned way is similar to the established methods in prior science, making it easier to compare and confirm information [1], [10], [11].

During each sEMG recording session, data were acquired for a total duration of two minutes. The protocol consisted of alternating 10-second epochs of rest (no voluntary movement) and 10-second epochs of repetitive movement (targeted shoulder or neck activity), repeated sequentially until the full two-minute period was completed. This design enabled comparative analysis of muscle activation and fatigue features across both rest and movement phases before and after the fatiguing intervention.



Figure 2 Electrode placement for surface EMG acquisition

D. Signal Processing and Feature Extraction

- Raw surface electromyography (sEMG) signals were visually scanned to detect and remove portions of the signal that had major motion artifacts or spikes (corruption). The retained signals were filtered with a fourth-order Butterworth bandpass filter with cutoff frequencies of 20–450 Hz in order to eliminate motion artifacts and high-frequency noise. The filtered signals were divided into consecutive waveforms of 10 seconds, being the phases of rest and movement, in both the Normal (baseline) and Fatigued condition.

To eliminate the inter-subject variability and make a meaningful comparison between conditions, a data normalization process was applied as a preprocessing step before the feature extraction process. For each subject, sEMG features obtained in the Fatigued condition were expressed for respective values obtained in the Normal (baseline) condition. This normalization procedure included mathematical scaling only and required no statistical hypothesis testing. Statistical comparisons between Normal and Fatigued conditions have been done using paired t-tests with the level of significance fixed at $p < 0.05$ for amplitude-based features

All signal processing and feature extraction procedures have been implemented with R2022b version of MATLAB (The MathWorks, Natick, MA, USA). Three features of sEMG often employed were extracted for every epoch:

- Root Mean Square (RMS): found as the square root of the mean of the squared values of the signal, which is the overall level of muscle activation.
- Median Frequency (MDF): calculated from the power spectral density computed using the Welch's method: is defined as the frequency that divides the power spectrum into two equal halves. MDF-specifies information about the spectral characteristics of the sEMG signal that is very often studied in the case of fatigue analysis.
- Integrated EMG (IEMG): is the integration of the rectified signal of expanded curvature and sEMG into each epoch of data as a representation of the total electrical activity in the muscle.

All processing steps were automated using custom, Matlab scripts so that there was consistency in processing among subjects and muscles. The parameters RMS, MDF and IEMG have been used extensively in previous ergonomic and biomechanical research to describe neuromuscular response and fatigue to repeated tasks [2], [15].

IV. RESULTS

The data section of this report summarizes the comparative analysis of the neck and shoulder muscle activity of the Normal (baseline) and Fatigue (post-exercise) conditions. In order to assure statistical reliability, and to compensate for inter-subject variability in the changes of skin impedance, normalization of the features was applied. The most important information was

gathered with Root Mean Square (RMS), Median Frequency (MDF), and Integrated EMG (IEMG).

A. Signal Visualization and Epoch Segmentation

Figures 2 and 3 shows raw EMG signals for Trapezius and Sternocleidomastoid (SCM) muscles. Visual inspection can be used, but to do this it is necessary to observe a clear change in the signal characteristics, including the Fatigue condition where the amplitude bursts and the signal density are higher than the Normal condition. This visual evidence matches the quantitative analysis to confirm that the protocol causing fatigue was successful at achieving physiological changes in the muscle fibers.

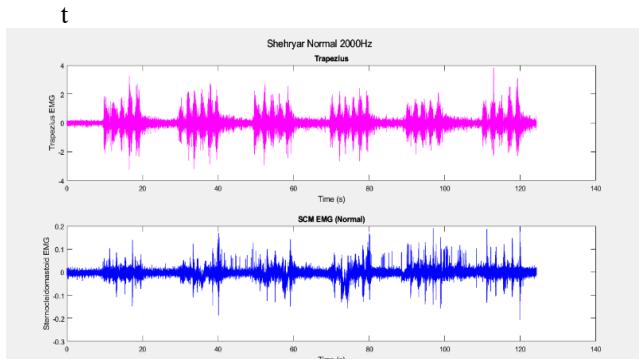


Figure 3 pre-fatigue sEMG signals from (top) trapezius and (bottom) sternocleidomastoid (SCM)

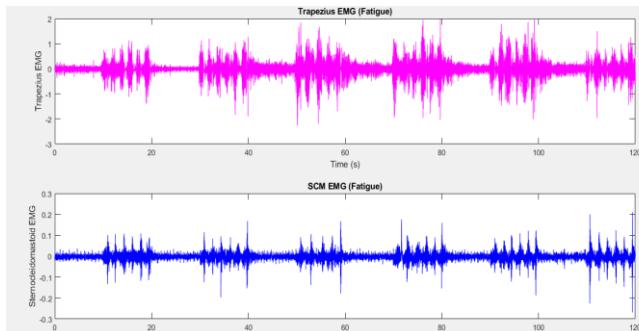


Figure 4 sEMG signals from (top) trapezius and (bottom) sternocleidomastoid (SCM) muscles under fatigued conditions.

B. Statistical Comparison and Tables

Figure 5 and Table 2 Summarize the normalized changes in the sEMG features ($N=7$). The Normal condition is taken as 100% baseline. A statistically significant increase ($p < 0.05$) was observed in RMS (+53.9%) and IEMG (+80.1%) from the Normal to the Fatigued condition ($N = 7$).

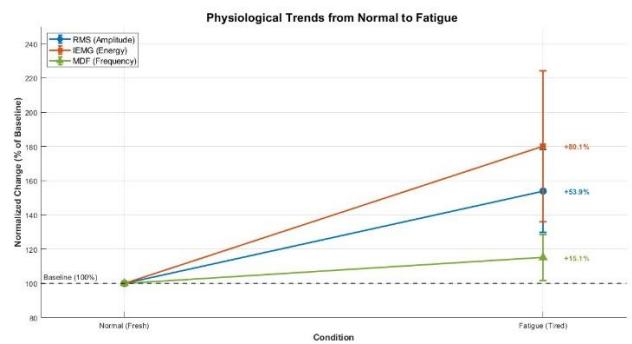


Figure 5 Normalized trends of surface electromyography (sEMG) characteristics during the dynamic fatigue protocol ($n=7$). The data is brought to the original set of the normalized form without fatigue (Normal) set at 100%. The Fatigue condition shows the concomitant increment of the RMS amplitude (Blue; +53.9%), Integrated EMG (Orange; +80.1%), and Median Frequency (Green; +15.1%). Error bars- The standard deviation (SD). The positive movement in all parameters implies the existence of the compensatory mechanism with the central nervous system increasing the recruitment of motor units and force output in order to maintain the task performance in the presence of physiological fatigue.

Table 2 Comparison of sEMG features between Normal (baseline) and Fatigue conditions ($n=7$)

Feature	Condition	Mean Value	% Change (Mean \pm SD)	Interpretation
RMS (mV)	Normal	0.103	—	Baseline Motor Drive
	Fatigued	0.166	+53.9% \pm 24.1%	Compensatory Motor Unit Recruitment
IEMG (mV·s)	Normal	1840	—	Baseline Energy
	Fatigued	3314	+80.1% \pm 44.0%	Increased Neuromuscular Cost
MDF (Hz)	Normal	78.5	—	Baseline Firing Rate
	Fatigued	90.3	+15.1% \pm 13.5%	Compensatory Force Increase

Note: Whereas RMS and IEMG showed a definite fatigue-related reaction consisting of elevated neuromuscular activation, the Median Frequency (MDF) provided a growing pattern (+15.1%). In classical stationary isometric experiments, fatigue is normally linked with decrease in MDF as a result of decreasing the velocity of conduction in the muscle fibers. Nevertheless, spectral compression may be obscured by task-related force demand elevations in the dynamic and repetitive tasks. This exercise has shown that a concomitant rise in amplitude and frequency of the EMG signal denotes an increase

state of force and not fatigue as proposed in the Joint Analysis of Spectrum and Amplitude (JASA) framework by Luttmann et al [17]. This implies that when the fatigue developed, the subjects employed a compensatory mechanism and responded to the fatigue by raising the instantaneous force production to sustain the task performance, although the neuromuscular efficiency worsened.

C. Trends and Observations

a) RMS and IEMG (Amplitude Features)

A statistically significant increase was observed for the RMS (+53.9%) and IEMG (+80.1%) in Fatigue condition compared to Normal. This statistically significant elevation suggests that during this task the fatigue response was to recruit more motor units (spatial summation) by increasing the central nervous system (CNS) neural drive to maintain the needed mechanical output as the muscle fibers fatigued.

According to our study results and also as seen in other ergonomic and biomechanical studies [5], [6], [10], and [13], IEMG, and RMS values increased as successive movement epochs were completed.

While it was observed that the aggregate analysis ($N = 7$) showed a clear tendency for fatigue, inter-subject variability was found to exist. This heterogeneity is typical of dynamic office tasks where different individuals might use different strategies to compensate themselves (e.g. postures shifts) which are changing recruitment patterns of muscle with respect to standardized protocols in laboratory [4].

b) Median Frequency (MDF)

The MDF showed to have a positive trend or increasing trend rate of +15.1% from Normal to Fatigue. While classical isometric fatigue is usually associated with a decrease in MDF because of a slowing of conduction velocity, the dynamic nature of this protocol led to another outcome. This simultaneous increase in both the amplitude (RMS) and the frequency (MDF) indicates a state of Force Increase, rather than a state of spectral shift of purely spectral nature. According to the Joint Analysis of Spectrum and Amplitude (JASA) framework proposed by Luttmann et al. [17], this pattern is consistent with increased recruitment of motor units involved in the response to force, which is in accordance with the compensation of the force during dynamic fatigue (as they have higher spectral frequencies) to compensate for declining neuromuscular efficiency and maintain task performance during dynamic fatigue.

RMS and IEMG showed a clear increase from Normal to Fatigued condition suggesting heightened neuromuscular activation and mechanical loading for elevation of metabolic cost consistent with a compensatory fatigue response. On the other hand, MDF recorded an upward trend (+15.1%). While over sustained, isometric-type fatigue, MDF is usually decremented, whereas dynamic and repetitive tasks may result in force-related spectral changes occur [17]. According to the Joint Analysis of Spectrum and Amplitude framework, therefore, a simultaneous rise in EMG amplitude and frequency is a sign of a compensatory force increase and not necessarily fatigue in the proper sense. This suggests that as they

accumulated fatigue that participants increased instantaneous force output to maintain task performance.

Therefore, MDF was not taken as an indicator of fatigue reflecting an amplitude of a quality of movement, but a marker of force modulation when assessed together with amplitude-based features.

c) Data Integrity and Subject Exclusion

First, the data was obtained from ten participants. Prior to the aggregate analysis, a rigorous signal quality check was made in order to confirm the "Normal" vs. "Fatigue" trends. While 7 subjects had consistent physiologic fatigue responses, 3 subjects were removed from the final analysis because of technical inconsistencies:

1. Signal Artifacts (Subject 5)

One of the subjects showed a contradictory trend with the RMS amplitude decreasing by 42.24% (Figure 6) in the fatigue state. A physiological fatigue response usually consists of an increase (recruitment) or slight decrease (force failure) in amplitude but if this becomes nearly total (> 0.02 mV), this signifies that the electrode has detached or wires have been disconnected during the dynamic movement. Consequently, this dataset was classified as a technical artifact and not as a physiological outlier and removed, in order to maintain data homogeneity.

2. Low Signal to Noise Ratio (Subject 2)

Another subject was excluded because he had insufficient baseline signal amplitude (< 0.02 mV) which prevented accurate normalization, so final statistical analysis was performed on the valid remaining data set ($n=7$), so that the reported trends are the results of genuine neuromuscular adaptations rather than errors of the instrumentation.

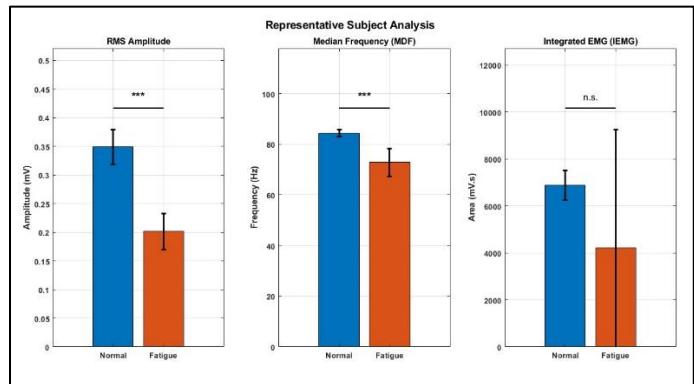


Figure 6 Statistical comparison for the sEMG characteristics for a representative subject excluded (Subject 5) exhibiting signal artifacts. The plots show comparisons between (Left) Root Mean Square (RMS) amplitude, (Center) Median Frequency (MDF), and (Right) Integrated EMG (IEMG) in the normal (baseline) condition and the post-fatigue condition. In comparison with the valid data set, this subject shows a

large non-physiological decrease in RMS and IEMG, which is indicative of a loss of technical signal (for example due to electrode detachment) or a failure of mechanical force. Consequently, this dataset proved to be an artifact and was removed from the final (aggregate) analysis because of ensure data homogeneity.

On the whole, the results suggest a greater neuromuscular activation and a greater modulation of the force by compensation in response to fatigue (reflecting a reduced efficiency instead of a reduced activity). In particular, the effects are noticed more in the trapezius muscle than in SCM, meaning shoulder muscles are more easily damaged while doing repetitive work at an office.

V. DISCUSSION

This study supports the fact that repetitive head and shoulder movements cause significant neuromuscular changes. By contrasting Normal and Fatigued, we were able to identify specific compensatory mechanisms which coincide with known ergonomic frameworks.

Amplitude Response (RMS & IEMG) The large impacts of RMS (+53.9%) and IEMG (+80.1%) suggest a greater neuromuscular cost to perform the task. This is in line with results by Dupuis et al. [1] and Sheikhhoseini et al. [4], who found that fatigued muscles need increased neural drive to maintain constant output. Fang et al. [16] describe this as spatial summation in which the central nervous system recruits more motor units to compensate for decreased contractility of fatigued fibers, which results in elevated metabolic demand observed in our subjects [5]. Frequency Response (MDF) and Force Increase Contrary to the spectral compression typical of static tasks, MDF increased by +15.1%. This finding is consistent with the Joint Analysis of Spectrum and Amplitude (JASA) by Luttmann et al. [17], which uses simultaneous increases in RMS and MDF as a Compensatory Force Increase. In the case of dynamic protocols, the neuromuscular system increases recruitment of high-threshold motor units linked with increased force demand, with the consequent significant increases in RMS and IEMG, accompanied by task-dependent modulation of MDF to avoid failure [15]. Under dynamic conditions, force-related spectral changes were shown to mask classical changes in spectral compression related to fatigue. The observed inter-subject variability further supports the interpretation of fatigue as a task-dependent compensatory process rather than a uniform physiological response

Ergonomic Implications These results suggest that office workers do not just "slow down" in fatigue but subconsciously increase muscular effort. Detecting this compensatory state is of critical importance in avoiding overuse injuries [10], [18] and is the reason for development of assistive technologies, such as passive exoskeletons, to offload the Trapezius during repetitive work [7], [14].

VI. CONCLUSION

Based on the findings, it is clear that workers suffering from repetitive tasks experience a lot of trapezius and SCM fatigue. It can be concluded that ergonomic interventions and careful monitoring would likely help since there significant increases in RMS and IEMG accompanied by task-dependent modulation of MDF.

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