Quantifying Activity of the Erector Spinae Longissimus Subgroup Using EMG During Prolonged Driving

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ABSTRACT: Prolonged driving has been associated with localized muscle fatigue, particularly in the lumbar region, posing safety and ergonomic concerns. This study investigates the dynamics of multivariate surface electromyography (sEMG) features to detect fatigue during extended driving sessions. EMG signals were recorded from the erector spinae muscles of seven subjects across two backrest inclination angles (100°, 110°) during real-world, multi-hour driving tasks. Spectrogram-based features, including mean frequency (MNF), median frequency (MDF), and root-mean-square (RMS), were extracted using a sliding-window method for analysis. Co-temporal trends in these features were analyzed to identify fatigue regions, marked by simultaneous decreases in MNF and MDF and/or increases in RMS. Paired t-tests were used to compare the two backrest inclination angles across subjects for each fatigue duration and fatigue event count. Results demonstrate that seat inclination angle significantly affects fatigue duration and number of events, with the 100° angle leading to notably more fatigue than 110° ($p<0.01$). This work could contribute a framework for time-resolved, EMG fatigue modeling in realistic driving scenarios.

ABSTRAK: Pemanduan terlalu lama dikaitkan dengan keletihan otot setempat, khususnya di bahagian lumbar, menimbulkan kebimbangan dari segi keselamatan dan ergonomik. Kajian ini mengkaji dinamika ciri permukaan multivarian elektromiografi (sEMG) bagi mengesan keletihan semasa sesi pemanduan jauh. Isyarat EMG direkodkan daripada otot erektor spina dari 7 subjek pada dua sudut kecondongan penyandar (100°, 110°) semasa aktiviti pemanduan sebenar berlangsung selama beberapa jam. Ciri berasaskan spektrogram, termasuk frekuensi purata (MNF), frekuensi median (MDF) dan purata punca kuasa dua (RMS) telah diekstrak menggunakan tetingkap-gelongsor. Corak serentak dalam ciri-ciri ini dianalisa bagi mengenal pasti kawasan keletihan, dibuktikan dengan penurunan MNF dan MDF serta/atau peningkatan RMS. Ujian-t berkembar digunakan bagi membandingkan dua sudut kecondongan penyandar merentas subjek bagi setiap tempoh keletihan dan bilangan kejadian. Dapatan kajian menunjukkan bahawa sudut kecondongan penyandar memberi kesan signifikan terhadap tempoh keletihan dan bilangan kejadian, dengan sudut 100° menghasilkan lebih banyak keletihan berbanding 110° ($p<0.01$). Kajian ini berpotensi menyumbang kepada satu rangka kerja pada model keletihan EMG beresolusi masa dalam senario pemanduan realistik.

KEY WORDS: *Prolonged Driving, Muscle Fatigue, Low Back Pain, EMG.*

1. INTRODUCTION

One critical factor affecting driving-induced low back pain is the driver's seat posture and seat inclination angle [1], as these directly affect muscle load and activation. The erector spinae longissimus subgroup plays a vital role in the stabilization of the trunk in this scenario. Muscle fatigue is defined as an exercise-induced decrease in the ability to produce force [1]. Prolonged sitting while driving often leads to low back pain and muscle fatigue [2]. Some studies investigated both physical and mental fatigue while driving. Physiological muscular fatigue has been best assessed through spectral analysis of the muscle's electromyography (EMG) signal. A number of studies show that it results in a downward trend in both mean frequency (MNF) and median frequency (MDF) [3, 4].

In [5], actual driving was conducted to study the effect of seat design. The study found that the suspended seat delayed the onset of significant discomfort compared to soft and firm seats. Pre- and post- endurance static tests were used to quantify fatigue. The study focused on seat types and did not consider inclination angle. In [6], surface electromyography (sEMG) of the neck and shoulder of professional and non-professional drivers was analyzed. Significant changes in electrical activity were found to exist in the left deltoid, bilateral trapezius, and splenius capitis muscle groups of all subjects. This change, however, occurred between the 1st and 15th minutes of the short drive, and it was on a driving simulator.

The study in [7] quantified muscle fatigue using spectral analysis of sEMG during driving and achieved an accuracy of up to 85% with a random forest model. The study considered only one seat configuration, did not conduct an inter-subject variability analysis, and investigated the trapezius muscle. In [8], sEMG features were derived using the Wavelet Packet Transform (WPT) and the Continuous Wavelet Transform (CWT) to classify segments into three levels: comfortable, fatigue, and painful. The study was done on a simulation. The study in [8] analyzed the effects of neck balancing and lumbar support, but the driving scenario and duration were only 1 hour, and the analysis used RMS only. In [9], they analyzed the influence of different seat adjustments on driving fatigue using the AnyBody system. The study found that a backrest inclination of 10 to 20 degrees reduced muscle activation and lowered L4-L5 compressive forces during steering tasks, while also moderating loads during pedal operation.

Despite existing research using sEMG, there are limitations, such as driving duration, lack of seat angle variation, or reliance on simulations. Previously, in [10], we studied the overall averaged trends in the changes in MNF and MDF over a three-hour drive. However, some MNF and MDF trend results contradicted each other. In this study, the relationship among features of the EMG signals and the resulting fatigue indicators is further studied in a time-resolved manner: how each feature indicates fatigue, and when they simultaneously indicate fatigue.

This paper is organized as follows: the next part describes the methodology, experimental protocol, data acquisition, and processing pipeline for EMG feature extraction and fatigue detection. This is followed by the presentation of results, highlighting fatigue duration and event counts across the two seat-inclination angles. The discussion section then interprets these findings.

2. METHODOLOGY

2.1. Subjects

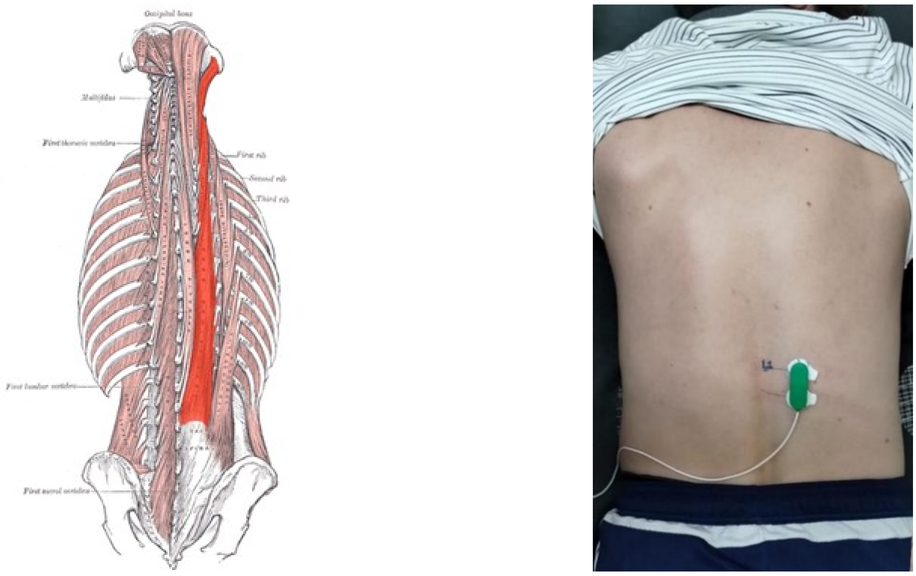
Seven healthy male subjects (mean age: 27.7 ± 5.3 years; mean weight: 64.3 ± 13.5 kg; mean height: 171.2 ± 4.0 cm) volunteered for the study. A sample size of 6 to 16 is common in similar studies [6,9,11], and this sample of seven subjects aligns with established research practice. Each subject completed three driving trials, each lasting approximately 3 hours, for a total of 63 hours. This study was approved by the IIUM Research Ethics Committee (IREC 2023-039). The subjects were: 1) aged between 20 and 30 years; and 2) free from symptoms of low back and cervical pain prior to participating in the experiment. All subjects held a valid driver’s license and provided written informed consent prior to their participation.

2.2. Experimental Setup

Before the experiment started, the seat backrest angle was set. The angle was measured between the pan and backrest as shown in Figure 1, using an inertial measurement unit (IMU) sensor (MPU6050), indicating the angle (θ) via an Arduino board. Each subject drove for three hours with θ = 100 and 110 degrees. The route consisted of a 73 KM lap through the section (Sungai Buloh - Ampang Jaya) of the Middle Ring Road 2, MRR2, Kuala Lumpur. Each subject was requested to drive at a maximum speed of 80km/h.

(a) Seat angle, θ (b) Seat angle set at 100° (c) Seat angle set at 110°

Figure 1. Seat angle, θ: the angle measured between the seat pan and the backrest.



(a) (b)

Figure 2. (a) The erector spinae group with the longissimus subgroup highlighted. (b) Sensor electrode placement.

To measure EMG, a Bitalino EMG sensor with an assembled BITalino Core BT/BLE board was used. Pre-gelled 24 mm polymer Ag/AgCl electrodes with a 20 mm inter-electrode distance were positioned vertically over the longissimus subgroup of the erector spinae muscle group. SENIAM guidelines dictated electrode placement at two finger-widths lateral to the spinous process of the L1 vertebra [11].

The longissimus muscle subgroup is between the iliocostalis and spinalis. It is the largest of the three columns. It originates in the lumbar region and attaches to the lower 9 or 10 ribs between the tubercles and angles, the transverse processes of C2 – T12, and the mastoid process of the skull. It extends the vertebral column, as shown in Figure 2, and the overview of the experiment is illustrated in Figure 3. The EMG data were read by a computer through Bitalino's OpenSignals software, which connects to the board via Bluetooth. The sampling frequency used was 1kHz. The data analysis was carried out on MATLAB R2024b.

2.3. Signal Processing

2.3.1. Signal Preprocessing

Prior to analysis, the EMG signals were filtered using a bandpass filter with cutoff frequencies of 30 Hz and 450 Hz, as recommended in [12], to remove low-frequency artifacts and high-frequency noise. To mitigate power line interference (PLI) commonly observed at 50 Hz and its harmonics in Malaysia, notch filters were applied at 50 Hz and its harmonics (100, 150, 200, 250, 300, and 350 Hz) [13]. The DC offsets of the signals are then removed by subtracting their means.

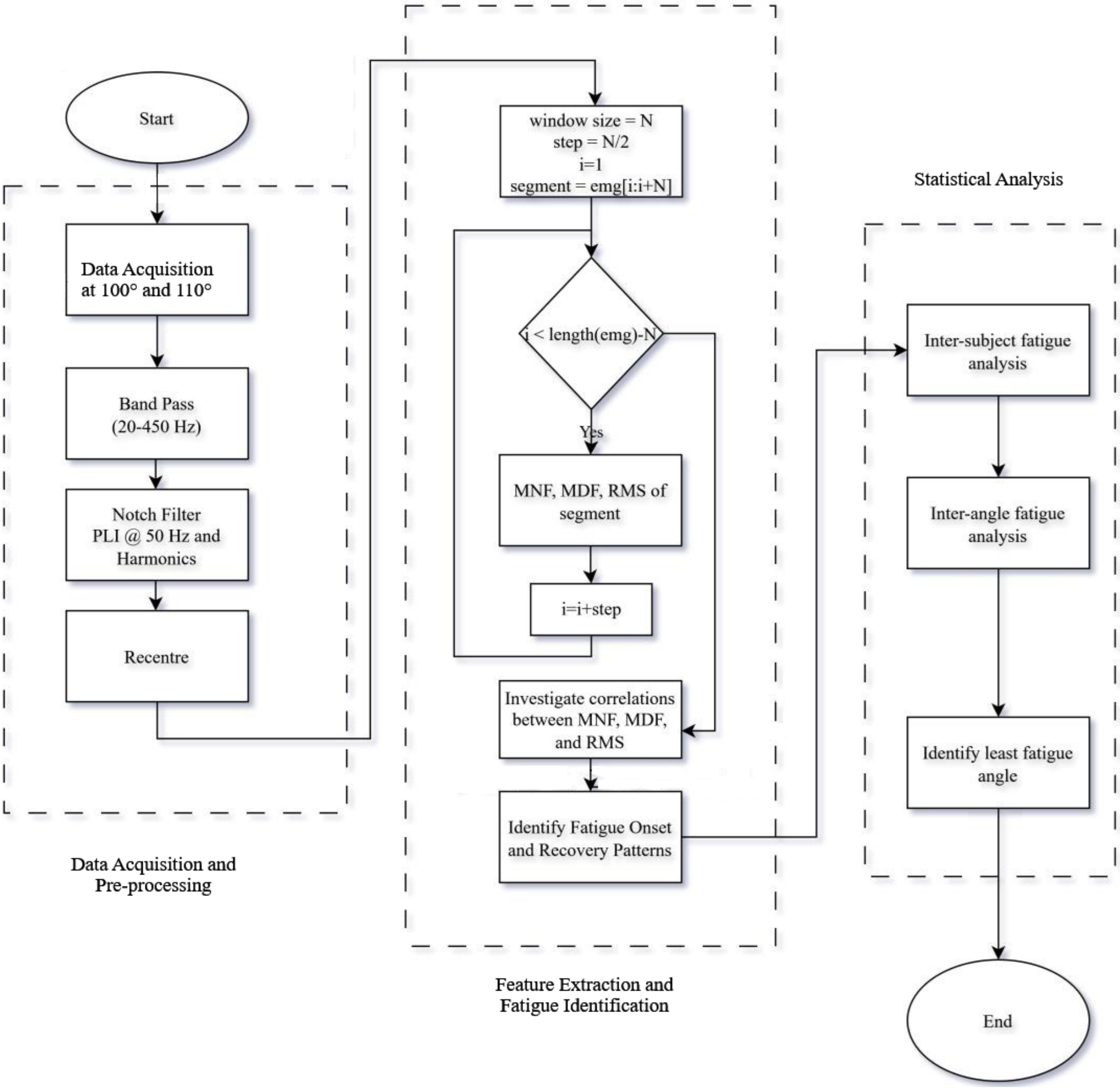


Figure 3. Flowchart of the fatigue assessment methodology.

The signals were analyzed using a 1-second sliding window. A 1-second window was selected based on the recommendation in [14], which suggests a window size of approximately 500ms for active muscle contractions and up to 1s for low-intensity muscle activity, such as with the longissimus in the driving scenario. For each 1-second window, the root-mean-square (RMS) was calculated to quantify muscle activation. Windows with RMS values below the overall mean RMS were excluded from further analysis, as they typically represent periods of minimal muscle activity. Removing these low-activation segments reduces the impact of baseline noise and improves the signal-to-noise ratio, thereby increasing the accuracy of feature extraction.

2.3.2. Feature Extraction

From each window, the five extracted features were RMS, MNF, and MDF, which measure central tendencies. These were computed as follows:

$$RMS = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{1}$$

$$MNF = \sum_{j=1}^{M} f_j P_j \,/\, \sum_{j=1}^{M} P_j \tag{2}$$

MDF is f_k such that

$$\sum_{j=1}^{k-1} f_j P_j < \frac{1}{2}\sum_{j=1}^{M} f_j P_j \text{ and } \sum_{j=1}^{k} P_j \geq \frac{1}{2}\sum_{j=1}^{M} P_j \tag{3}$$

x_i is the signal values within a specified moving window of size n. P_j and f_j are the power and the frequency at bin j, and M is the number of frequency bins.

2.4. Fatigue Markers

The features were first aggregated in 10-second averaging windows, with a sliding step of 5 seconds. Regions were marked as displaying fatigue if at least two of the following criteria were met:

1. A consistent downward trend in Mean Frequency (MNF)
2. A consistent downward trend in Median Frequency (MDF)
3. An increase or plateau in Root Mean Square (RMS)

For a minimum duration of 30 seconds (at least 6 consecutive windows) with at least 2 of the 3 conditions above met. The 30-second duration was selected to avoid noise effects at the low muscle activation levels used in [15,16].

For each trial, total fatigue duration was calculated by tallying the lengths of all identified fatigue episodes, and fatigue event count was defined as the number of distinct episodes detected. These summary metrics were then statistically analyzed.

2.5. Statistical Analysis

The total fatigue duration and number of fatigue events were summarized for each subject and seat angle. For each metric, the normality of paired differences between the angles (100°, 110°) was evaluated using the Lilliefors test. Paired t-tests will be used to compare the two angles when the normality assumptions are met; otherwise, the Wilcoxon signed-rank test will be used. Effect sizes were also calculated using Cohen's *d* to quantify the magnitude of differences and their practical significance.

3. RESULTS AND DISCUSSION

Patterns of regions indicating fatigue were intermittent. Figure 4 presents the results from a representative subject. No distinct trigger point is identified; instead, there is a gradual increase in the frequency of occurrence and duration of such regions. To provide a clearer view of short-term fluctuations, Figure 5 presents a zoomed-in segment of the same data, corresponding to the dotted box in Figure 4.

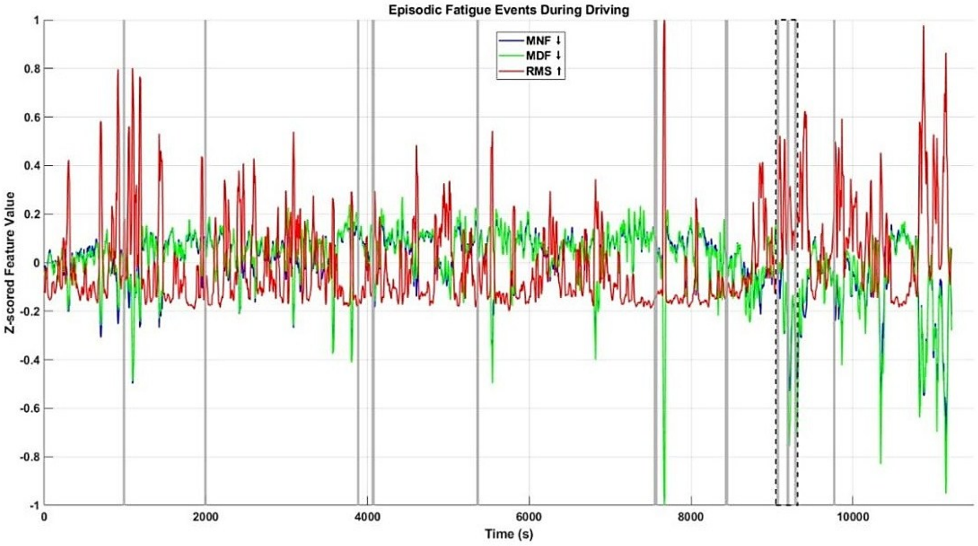


Figure 4. Intermittent regions where MDF, MNF and/or RMS indicate fatigue.

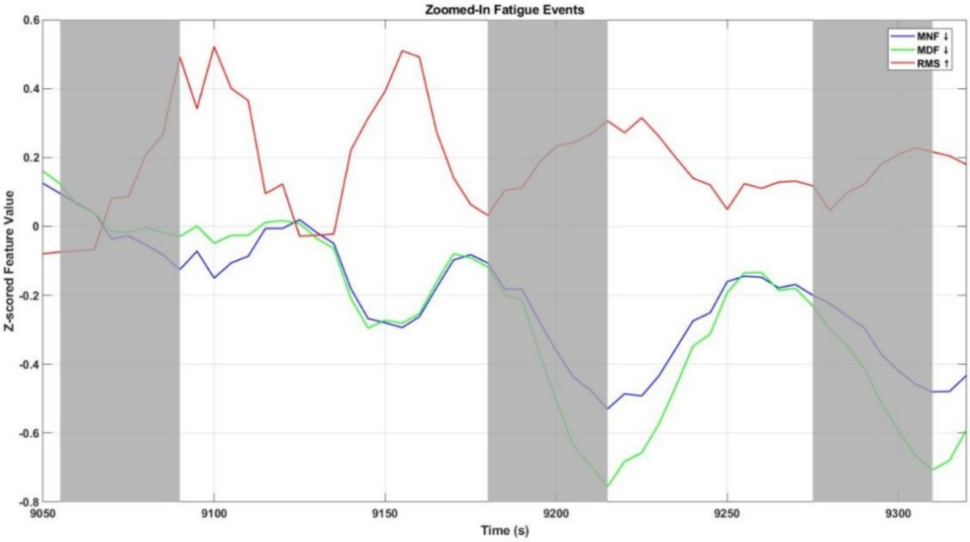


Figure 5. Zoomed-in view of Figure 4 (9050 ≤ t ≤ 9320 s) showing localized fatigue dynamics.

Table 1 presents the total fatigue duration and fatigue counts across all seven subjects and seat inclination angles. The mean fatigue duration for the two seat angles is shown in Figure 6: 1020.71 s at 100° and 661.43 s at 110 °.

Table 1. Summary of total fatigue duration and fatigue counts across subjects and seat inclination angles

Subject	Seat Angle (°)	Fatigue Duration (s)	Fatigue Events (counts)
1	100	785	24
	110	395	11
2	100	1125	29
	110	835	22
3	100	610	17
	110	350	10
4	100	1480	42
	110	1165	33
5	100	890	26
	110	525	16
6	100	625	18
	110	265	8
7	100	1630	41
	110	1095	30

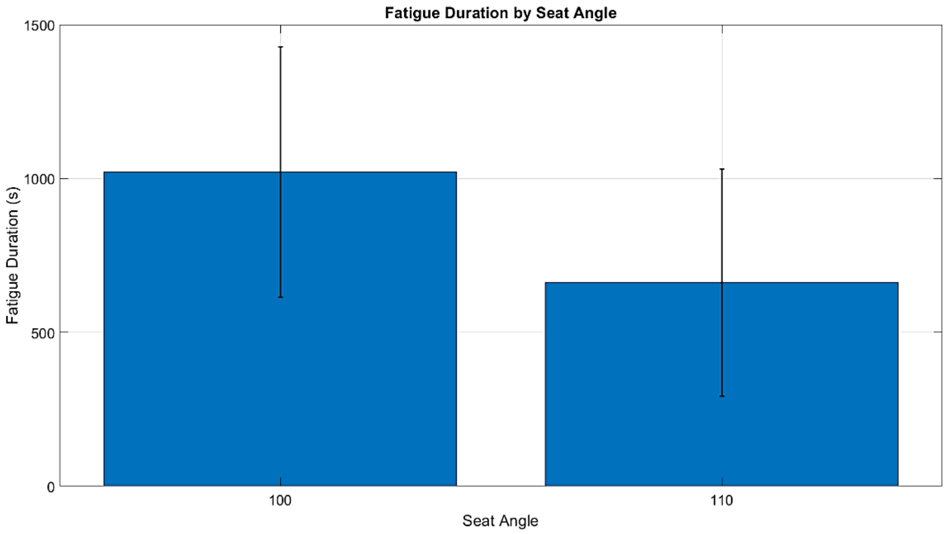


Figure 6. Total duration of fatigue regions for each seat angle.

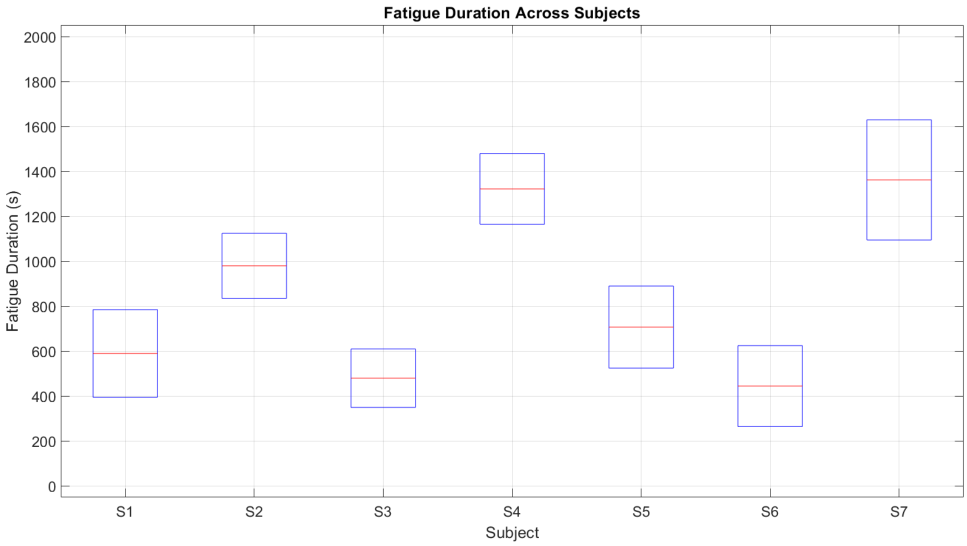


Figure 7. Total fatigue duration for each subject.

Inter-subject comparisons showed significant differences in both fatigue duration and the number of fatigue events, with p-values of 0.039 and 0.046, respectively. Figure 7 shows fatigue duration across all seven subjects. Some subjects (e.g., Subjects 4 and 7) showed longer and more frequent fatigue periods than others. This makes them clearly distinct when compared pairwise with selected subjects with shorter durations (e.g., Subject 6). However, other pairs of profiles have overlapping distributions. However, this is not generalized among all pairs of subjects.

The normality of the paired differences between seat inclination angles (100° vs. 110°) was confirmed using the Lilliefors test (Duration: $p = 0.359$; Events: $p = 0.500$).

Results of the t-test showed that fatigue duration was significantly shorter at 110° compared to 100° (t(6) = 10.576, $p < 0.0001$, 95% CI). The effect size was extremely large (Cohen's d = 3.997), indicating a practical, robust reduction in fatigue duration at the more reclined posture.

Similarly, the number of fatigue events was significantly lower at 110° than at 100° (t(6) = 11.783, $p < 0.0001$, 95% CI), with a large effect size (Cohen's d = 4.453). The total duration of fatigue regions, subject-wise, is shown in Figure 8.

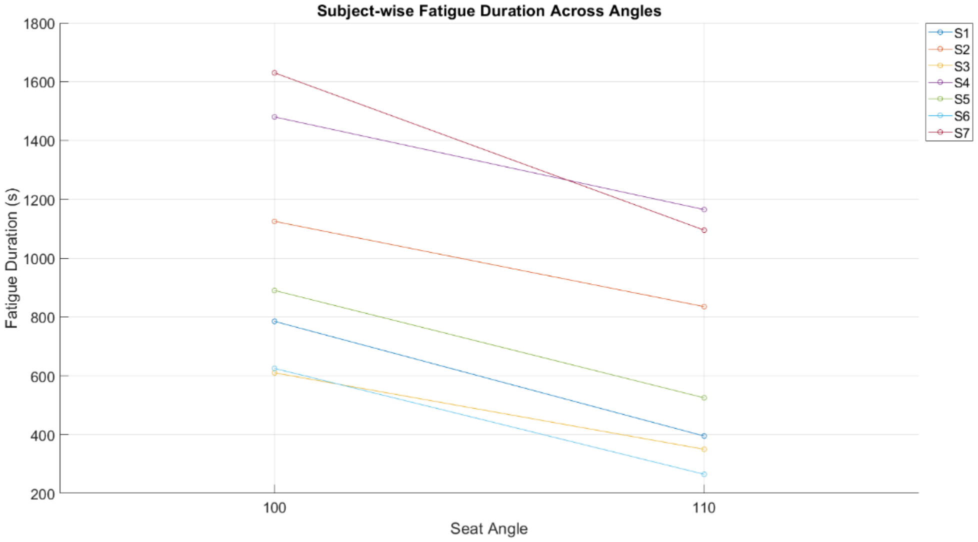


Figure 8. Subject-wise total fatigue regions duration vs. seat inclination angle.

This study found that the longissimus subgroup experienced less fatigue during prolonged driving at a seat inclination angle of 110° than at 100°. This is likely due to the effect of a more reclined backrest on reducing the load on the lumbar erector spinae and on load distribution, which in turn slows the spectral downshift (MNF or MDF) and limits the response in RMS increases [6, 17].

This study has some limitations. Since the analysis was limited to a single subgroup, the findings cannot be generalized to all lumbar muscles. Extending the investigation to include other muscle groups or subgroups may provide a more comprehensive understanding of their behavior under similar conditions. In addition, High-Density EMG (HDEMG) could offer deeper insights into spatial variations and simultaneous changes along the muscle itself. Finally, examining the synchronization of left and right subgroups may help clarify the role of the central nervous system (CNS) coordination in driving-related muscle fatigue.

4. CONCLUSION

This study found that a seat inclination angle of 110° was significantly more favorable for the erector spinae during prolonged driving compared to 100°. This finding may be applied in ergonomics to enhance driver comfort, for example, by optimizing lumbar support angles. Furthermore, this study contributes a framework for time-resolved, EMG fatigue modeling in realistic driving scenarios. In future studies, the use of HDEMG could provide more information on the muscle itself; recording background noise would improve noise cancellation, and examining the left-right muscle synergy could clarify how these muscles cooperate.

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