Detection of Local Muscle Fatigue in Writing Task Using Surface Electromyography

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We hereby recommend that the dissertation prepared under our supervision by **Nadir Abbas Registration No. 00000278004** titled **Detection of Local Muscle Fatigue in Writing Task using Surface Electromyography** be accepted in partial fulfillment of the requirements for the award of MS Biomedical Engineering degree with Grade (___)

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Copyright Statement

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Mr. and Mrs. Ghulam Sarwar

Abstract

While doing a cognitive job over extended periods causes muscle fatigue, defined as "a situation in which a muscle's capacity to produce maximum voluntary activity, or to perform a series of repetitive motions, is decreased." It occurs while muscle contraction overshoot’s the ability of the tissue substrate and oxygenation. This condition of fatigue can be improved by resting or performing specific workouts. In the Electromyography (EMG) signal, fatigue is known to produce an increase in amplitude and a reduction in spectral line frequencies. The focus of this research was to identify how muscle fatigue occurs in the forearm muscle following both handwriting (HW) and typewriting (TW). Surface EMG signals (sEMG) for both HW and TW were recorded before and after the task performance. These trials were carried out by allowing participants to write approximately 400-500 words on different days. Three muscles were discovered to be involved in handwriting and typewriting: Flexor Carpi Ulnaris, Flexor Carpi Radialis, and Extensor Carpi Radialis. The surface EMG signal was recorded using four different movements. In both writing studies, the median frequency (MDF) was utilized to measure muscle fatigue. The median frequency's power spectrum was compared before and after the work was completed, as well as with the HW and TW outcomes. The findings revealed that following task completion, the median frequency of the EMG signal decreases, indicating that local muscular fatigue has developed in all of the selected muscles. The results showed that HW produces more fatigue than HW since the median frequency values are considerably lowered after the HW activity with a probability ($p = 0.0053$) value, whereas TW remained statistically insignificant with ($p = 0.1751$).

Key Words:

Local Muscle Fatigue; Surface Electromyography (sEMG); Median Frequency (MDF).

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Fatigue is a normal side effect of prolonged intense exercise [1]. According to prior research, there are two forms of fatigue: objective and subjective fatigue [2]. Objective fatigue is caused by engaging in physical activities, resulting in a reduction in the ability to execute mechanical activity. Subjective fatigue, on the other hand, is caused by hard mental work and results in a decrease in mental clarity and alertness [3]. In this study, we look at how objective fatigue affects writing tasks, where physically demanding activities cause an interruption in the generation and use of metabolic energy [4]. As a consequence, metabolic waste accumulates at the cell membrane, leading the body's natural balance to be disrupted [5].

Previous research on detecting muscle fatigue has shown that fatigue occurs frequently before muscular injuries when muscles are at their most susceptible [6]. Fatigue-induced injuries are a kind of injury that can result in several problems, including a significant loss of muscular strength and flexibility [7]. As a result, the goal of our research is to identify fatigue during writing tasks to decrease the risk of fatigue-related accidents. Fatigue, however, lowers muscular endurance over time until it surpasses the muscle's stress tolerance, resulting in injury [8].

The purpose of this research was to investigate local muscle fatigue that developed in the forearm muscle during the writing activity and determines if handwriting or typewriting produces more fatigue. For this purpose, surface Electromyographic (sEMG) signal was recorded from the forearm muscle, Flexor Carpi Ulnaris, Flexor Carpi Radialis, and Extensor Carpi Radialis muscle [9].

1.1. Background

According to studies done in the early 1900s, during exercise, the buildup of lactic acid in the fermentation route also causes muscular fatigue [10]. For centuries, this has been the accepted understanding of muscle physiology [11], however, new research has discovered that muscle fatigue can occur in different ways based on the specific type of activity done [12]. According to one idea, the muscle begins to fatigue as the concentration of phosphate in the cell's cytoplasm rises. Muscle failure occurs when phosphocreatine is broken down into phosphate and creatine molecules [13]. As a result, the force during the construction of cross-bridges muscular stretching will be reduced. The reason behind the slowing down velocity of muscle during muscle stretching is the development of ADP and this is another modern explanation for muscle tiredness [11], [14]. Finally, it has been considered that muscular fatigue is caused by a lack of glycogen in the body. The mechanism behind why this is happening is unknown to researchers [10]. As previously stated, athlete tiredness is strongly linked to the sort of activity they undertake. The kind of damaged muscle fibers affects fatigue and the rate of tension inside a muscular contraction [10], [13].

1.2. Problem Statement

When you initially start exercising or undertaking activities, your muscles feel strong and powerful. However, with time, your muscles may get weaker and tired, particularly if you repeat exercises. This syndrome is sometimes referred to as muscle weariness. Muscle tiredness indicates that your muscles' ability to function is decreasing with time. It's usually associated with exhaustion, especially after strenuous activity or exercise. When you're fatigued, the force with which your muscles move decreases, making you feel less powerful. Muscular fatigue causes you to utilize less force when performing muscle movements. Unless your fatigue does not improve with rest, this symptom is frequently regarded as insignificant. Muscle fatigue might be a sign of a more serious disease in more extreme situations. This illness, if left untreated, can lead to overwork and increase your risk of injury. To avoid major damage, it is important to recognize the onset of muscular fatigue.

1.3. Objectives

The prime objectives of the study are to:

1. Identifying forearm muscle tiredness after writing task to minimize fatigue-related hazards.
2. In comparison to earlier techniques, this strategy is more practical and realistic in everyday life.
3. A variety of data collecting and processing issues and solutions are highlighted.

1.4. Areas of Application

- **Training Optimization Departments**

  Muscle Fatigue Monitoring and Muscle Disease Diagnosis

- **Injury Prevention Departments**

  Physical Medicine (Doctors and Physiotherapists)

- **Rehabilitation Departments**

  To Detect Acute and Chronic Injuries

1.5. Thesis overview

In this thesis, chapter 1 includes the introduction and explanation of the problem along with a proposed solution. Chapter 2 includes the work that has been done in the same or related entity. Chapter 3 provides information about the materials and methods used for this study. It contains all the methods and procedures used to detect muscle fatigue and processing of the recorded EMG signal. Chapter 4 includes the results obtained from the EMG signal. Chapter 5 consists of the discussions of obtained results and finally a conclusion of this whole work. Chapter 6 enlists all the sources from where the material has been obtained and properly-referenced.

Chapter 2: Literature Review

Repetitive or prolonged activity, short work cycles, and specific muscle loadings are all common causes of muscle fatigue [15]. Muscle fatigue causes a forced decline, which is created by the muscle itself [16]. Muscle changes metabolically, structurally, and energetically and this is caused by a shortage of oxygen and nutritive nutrients provided by blood [16], [17].

Muscle exhaustion happens when the capacity of a muscle to produce force is reduced. It can be caused by hard exercise, but it's also conceivable that creates obstacles to or interferes with the various phases of muscular shrinking cause atypical tiredness [16], [18]. Muscle tiredness caused by two factors [19]:

i. Neuron's ability to produce a long signal
ii. Muscle fiber's reduced ability to stretch

2.1. Muscle Stretching

Muscle contraction happens when tension-generating regions within muscle cells are activated [20]. In physiology muscular shortening is not usually associated with muscle stretching, the reason is that without changing the length of the muscle, tension can be produced [21], [22].

Muscle contractions can be defined by the length and tension of their contractions. Isometric contractions occur when muscular tension fluctuates while muscle length remains constant [24]. If the muscle tone remains constant during the contraction the contraction is isotonic. Concentric contractions occur when the muscle length shortens; eccentric contractions occur when the muscle lengthens [23], [25].

2.2. Neural Fatigue

Nerves are in charge of regulating muscle contractions, defining the number, sequence, and power of contractions. Most motions need considerably less effort than a muscle might generate, therefore nerve fatigue is rarely an issue [16], [26]. During highly strong contractions near the upper limit of a muscle's potential to produce force, nerve fatigue (enervation, or a decrease in nerve signal) can be a limiting factor in untrained persons [18].

In starting strength trainers, The capacity of the nerve to maintain a high-frequency signal is the most important limiting element in a muscle's ability to create force [27]. The frequency of the nerve's signal decreases after a time of maximal contraction, and the force exerted by the contraction decreases [28].

This type of fatigue can be explained by a fatigue model that is neuromuscular fatigue model, which is by far the most important fatigue in terms of the muscle fatigue scope under investigation in this study [29]. It may be used to explain fatigue in a variety of ways, the most common of which include muscular stimulation, recruitment, and contraction, as well as electrical impulses transmitted from the brain. These variables have an impact on muscle performance during exercise [30]. Fatigue in this concept is caused by the failure of three key sequential components, which react in the transmission of all instructed motion. This is thought to be a mechanism that protects muscle fibers from severe injury. Different forms of neuromuscular fatigue are identified in the three main sections of that journey [31]–[33]. As illustrated in Figure, they are taken into consideration depending on the locations of command chain failures on muscle contractions. When looking at the signal channel, you can see neuromuscular exhaustion models in the figure. It is made up of three consecutive models, which are as follows:

1. It illustrates a central activation failure theory from the top of the figure. A decrease in central activity is linked to changes in neurotransmitter concentrations or being stimulated by afferent sensory feedback.
2. A neuromuscular propagation failure can be seen in the middle of the diagram. According to this theory, changes in ionic pump activity and/or the motor neuron pool are connected to a decrease in membrane excitability.
3. It illustrates a peripheral failure theory from the bottom of the picture. This idea is linked to the failure of actin and myosin's coupling function. Calcium levels in the muscle during inhibition are considered to be the reason.

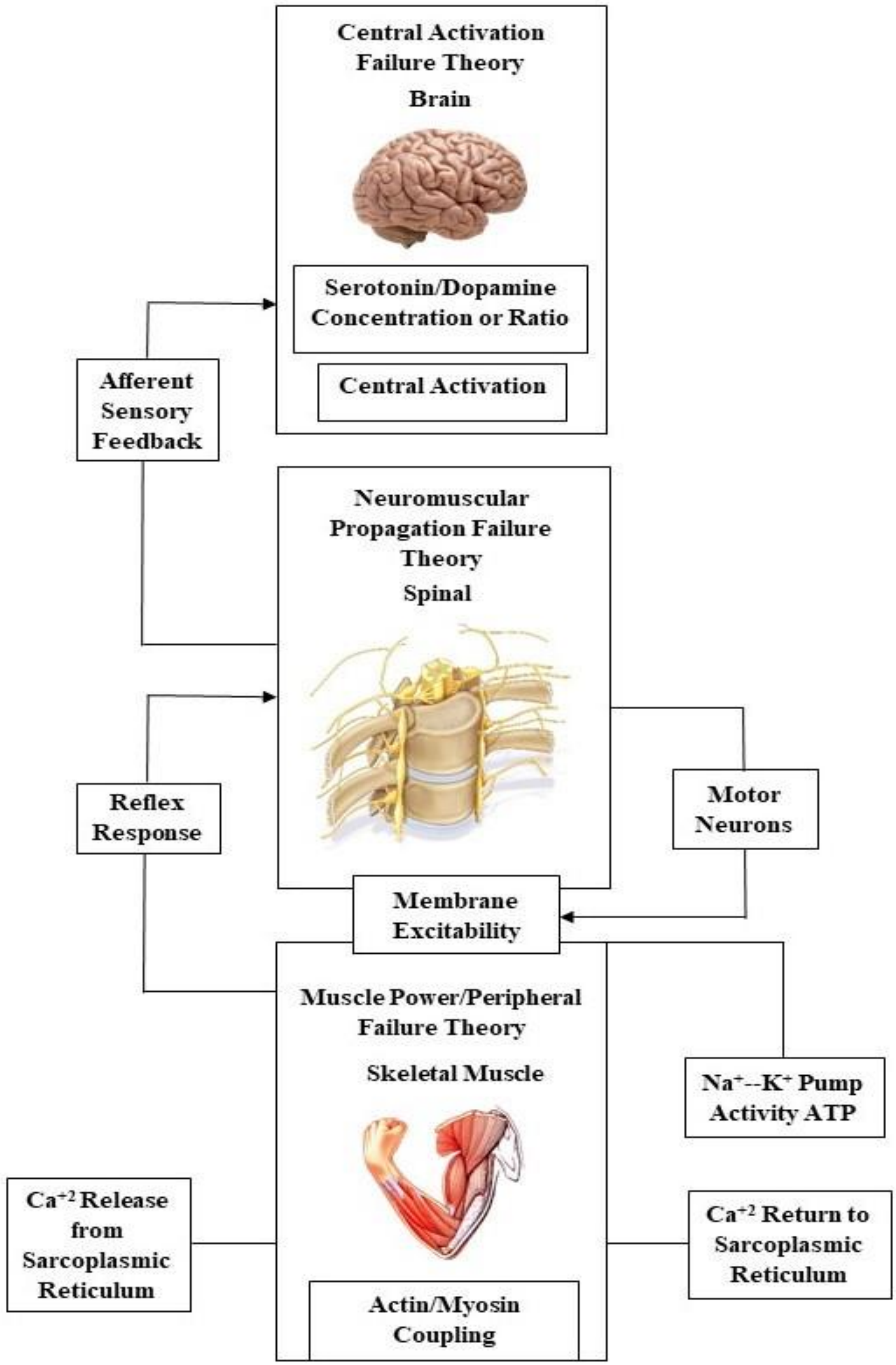


Figure 1: Neural Fatigue Model

2.3. Metabolic Fatigue

The term "metabolic fatigue," though not frequently used, refers to a reduction in contractile strength induced by the indirect consequences of two primary causes [34]:

1. Fuel (substrates) shortage inside the muscle cell.
2. Chemicals (metabolic enzymes) accumulate inside muscle fibers, obstructing calcium (Ca^{2+}) release or calcium's capacity to stimulate muscular contraction

2.3.1. Substrates

Muscle contractions are powered by substrates inside the muscle. Adenosine triphosphate (ATP), creatine phosphate, and glycogen are examples of these compounds [35]. According to the sliding filament hypothesis, ATP attaches to the myosin head and produces ‘loosening,' which leads to shrinkage [29], [35].

One of the reasons for metabolic fatigue is a lack of nutrients. During exercise, substrates are exhausted, resulting in a shortage of intracellular energy sources to power contractions. To put it another way, the muscle stops contracting owing to a lack of energy [36].

2.3.2. Metabolic Byproducts

Metabolic substances are compounds generated as a result of muscle contraction (usually waste products). These byproducts include chlorine, lactic acid, adenosine diphosphate (ADP), potassium, and magnesium (Mg^{2+}). Metabolites can cause metabolic fatigue in muscle fibers either directly or indirectly by interfering with calcium (Ca^{2+}) release from the sarcoplasmic reticulum or by reducing the calcium sensitivity of contractile components actin and myosin [37].

2.4. Molecular Mechanism

Muscle fatigue might be caused by certain chemical changes that occur in the body as a result of prolonged activity. The "leaky" intracellular calcium causes a skeletal muscle shift during activity. Muscle fatigue and reduced exercise capacity may be caused by these "leaky" pathways [38].

2.5. Performance Impact

Fatigue has been proven to have a major influence on performance in nearly every person who engages in any activity. In research studies, it was shown that participants had decreased the muscle ability to perform over a long period [39]–[42].

2.6. Electromyography (EMG)

Electromyography is a graphical method that quantifies electrical impulses delivered to muscle fibers by motor neurons, allowing scientists to study muscle activation in several situations [43]. In general, fatigue studies have demonstrated that during a fatiguing procedure, EMG data rises, yet fatigued individuals activate fewer muscle fibers in power tests [44], [45].

When using EMG to measure fatigue, median power frequency is frequently used. Filters are used to filter raw EMG data and cleaned to remove noise, then appropriate time frames are obtained. [46], [47].

For each data window, the median frequency is computed. Concerning time, a decrease in the median, frequency is an indication of tiredness [48], [49]. Motor unit action potentials follow a similar repolarization pattern, having faster motor neurons operating and then decreasing, and nervous system propagation rate decreasing with time, all of which lead to tiredness [50], [51].

Chapter 3: Methodology

3.1. Participants

A total of 12 healthy people volunteered to the dataset used to determine local muscle fatigue. All of the individuals were males between the ages of 21 and 30, with a mean age of 25.5 years. They were all healthy and had no history of injury or other musculoskeletal issues. Two sessions were used to record the data. The subjects were asked to perform Hand Writing (about 400-500 words) in the first session, and then Typewriting the same words (approximately 400-500 words) on a computer or laptop in the second session. The examination was explained to all of the subjects, and their involvement was planned. All subjects were given a written agreement concerning the study, and they had the right to leave at any moment for any reason. The experimental protocol for this investigation was authorized by the local ethical council (SMME-NUST/ IRB/2021-02/38) and followed the criteria of the Declaration of Helsinki from 1975.

3.2. Recording Surface Electromyographic Signal (sEMG)

Using the surface electrode on different muscles, a raw EMG signal was acquired from the forearm's surface. Surface EMG electrodes (Ambu Neuroline 720 surface electrodes, REF 75000-S/25, Australia) were used to acquire EMG signals from the Flexor Carpi Ulnaris, Flexor Carpi Radialis, and Extensor Carpi Radialis muscles [9] over the belly of the muscle. As a reference, a moistened wrist band was placed near the carpus of the opposite hand. Six surface bipolar electrodes (two electrodes for each channel) were inserted around the length of the forearm at equal distances (2 cm) [52]. Surface electrode positions were indicated with a skin marker to ensure proper electrode insertion for the subsequent recording of the EMG signal. Before placing an electrode on the surface of the muscles, the electrodes were unpacked with sterile gloves and the skin was carefully cleaned with an alcoholic swab. The sampling frequency was 2048 Hz and the EMG signals were magnified with a factor gain of 10,000 (EMG-USB2+, OT-Bioelettronica).

3.3. Experimental Setup

Two parts of the process were chosen to detect local muscle fatigue (HW and TW). We hypothesized that either tiredness formed or did not develop in the active muscles following task execution and that we could tell whether handwriting or typewriting generates more fatigue. First, the signal intensity was assessed after the electrodes were placed on the dominant forearm, and then the signal recording methodology was performed. Each participant was given a thorough explanation of the study methodology, and the subjects were controlled during the recording session using a viewable signal image.

The sEMG signal was recorded before the task was completed (HW on a paper). Subjects performed four active motions (closed hand, open hand, pinch grip, and lateral grasp) and a resting-state motion during the sEMG signal recording session (no motion). The subject was then requested to write 400-500 words on a piece of paper, with the sEMG signal being acquired once the assignment was completed. A typewriting session on a computer or laptop followed the same method. The amplifier "OT Bio Electronica" and "OT Bio Lab," an open-source collecting program, were utilized to acquire data. Data were obtained on four separate motions, each lasting six seconds and being repeated six times. In one day, one experimental session was directed. The recording session lasted around 288 seconds in total, with a 48-hour delay between the first and second sessions. The electrodeposition was indicated on the forearm for the appropriate placement of electrodes to record the signal for the second session.

Four parameters were used to determine the local muscular fatigue created in the forearm muscle as well as the reaction time (working ability):

1. Any typewriting experience (as a first-time operator)
2. Working Frequency (Words per Minute): 400-500
3. Posture (Muscular Disturbance)
4. Recovery

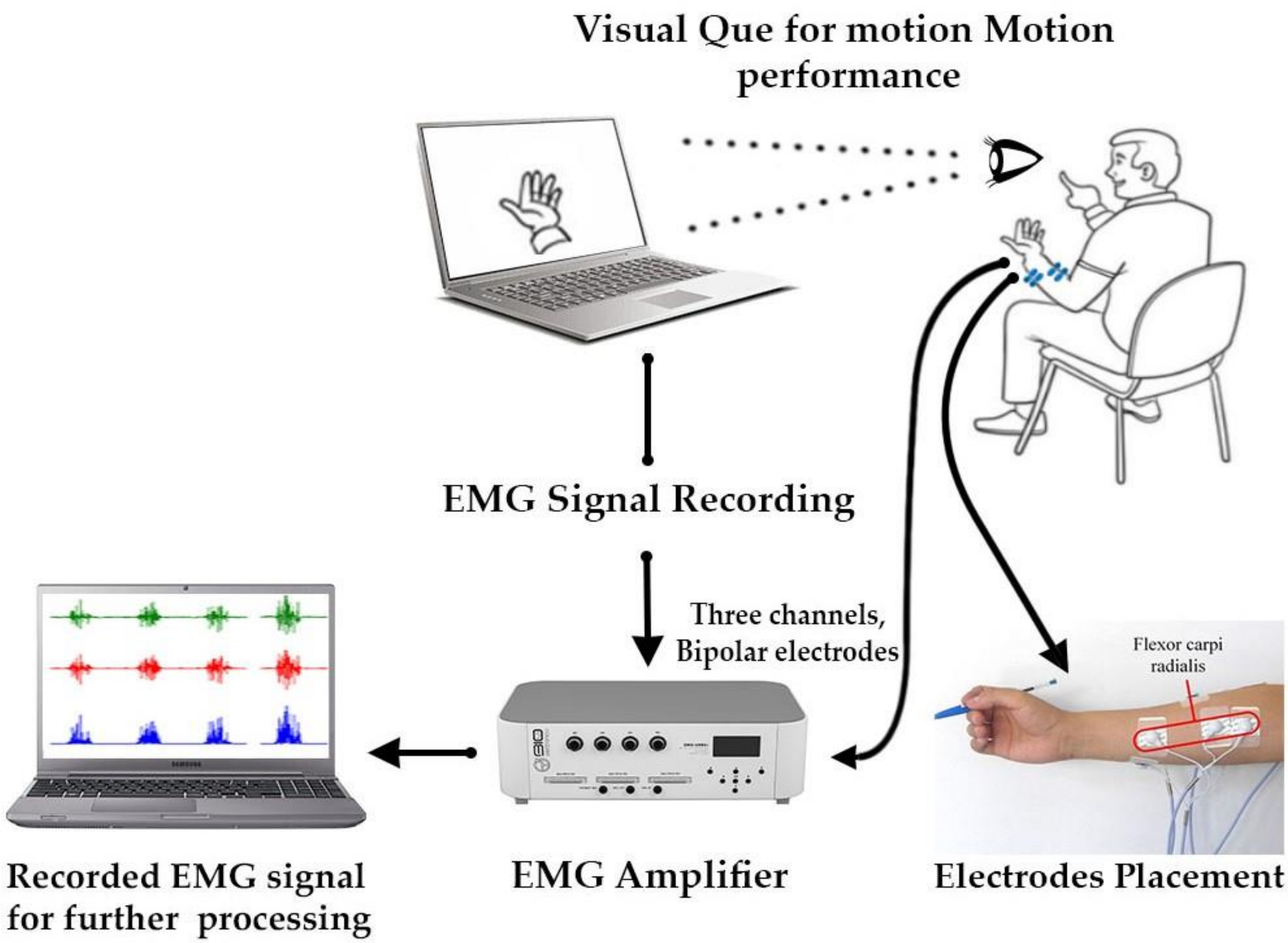


Figure 2: Experimental Procedure

3.4.1. Data Analysis

3.4.1. Pre-Processing

To eliminate noise from recorded EMG signals, signals were transmitted through a bandpass filter with cut-off frequencies of 20 and 500 Hz, as well as a Notch filter from 49–51 Hz using a second-order Butterworth filter with no phase shift. A series of six-second repetitions of each motion class were extracted from the signal, the remainder of the EMG signal was eliminated to get just the contracted muscle activation in the signal.

3.4.2. Processing EMG Signal

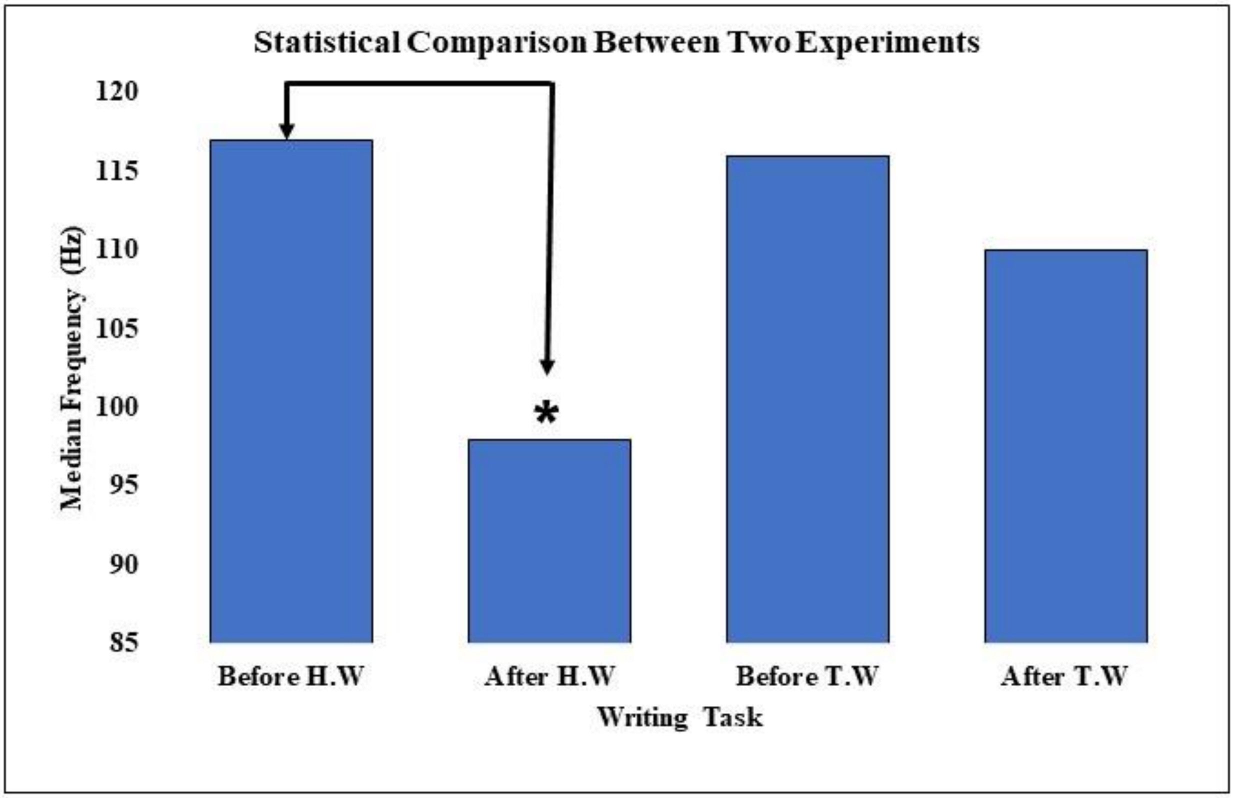
The muscles can provide a wealth of information. Because raw EMG data had a lot of noise and information, features were removed from the signal to use it as a conclusion signal [53]. The EMG signal can be represented in the time domain, frequency domain, time-frequency domain, and time-scale domain. The frequency domain, on the other hand, provides more information than the other domains for detecting muscle fatigue [54]. For determining the severity of local muscle fatigue, the most valuable and widely used frequency domain features [7] are mean frequency (MNF) and median frequency (MDF) and commonly used for fatigue detection through EMG signal. sEMG signals can detect muscular fatigue in a variety of situations, including continuous cycling runs, children with cerebral paralysis experience muscular weariness., and muscle fatigue when playing computer games. Wavelet analysis, zero-crossing rate (ZCR), RMS, and MNF and MDF are some of the classic and innovative signal analysis methodologies that have been used [55]. Since muscle fatigue causes a downward change in the frequency range of the EMG signal [56], MNF and MDF have been regarded as the best quality level for muscle fatigue measurement with surface EMG signals. In our situation, we employ EMG to assess muscular fatigue in the writing task using the MNF and MDF approaches.

3.4.3. Statistics

For the statistical analysis of fatigue developed in the handwriting and typewriting task performed and to differentiate either the more fatigue is developed in the handwriting task or typewriting task, two-way repeated measures of analysis of variance (ANOVA) were used. For all the statistical analysis a probability value (p-value of < 0.05) was used.

Chapter 4: Results

Significant differences between the groups were discovered using a two-way repeated-measures analysis of variance (ANOVA) with the four classes (Before HW, After HW, Before TW, and After TW) with ($p = 0.0053$) for HW and ($p = 0.1751$). The distinction between class 1 and class 2 is significant., which are Before HW and After HW, according to post-hoc analysis using Tuckey's Honest correction for multiple comparisons. The comparison between the two tests is presented in the bar graph below.



Error Bars = 95% Confidence Interval (CI)

Figure 3: Statistical comparison between two experiments, * sign shows decline in median frequency

According to the findings, HW causes more fatigue than TW because the MDF values are significantly lower after the HW task compared to TW, which remained nearly identical.

4.1. Median Frequency (Hz) for the Handwriting

The MDF values for before and after HW task performance are summarized in the following table:

Table 1: Variation of Median Frequency for Handwriting

Subjects	Median Frequency (Hz) Before HW	Median Frequency (Hz) After HW
1	127	94
2	139	92
3	100	80
4	117	93
5	103	90
6	126	105
7	100	88
8	100	91
9	100	84
10	187	175
11	110	95
12	100	88

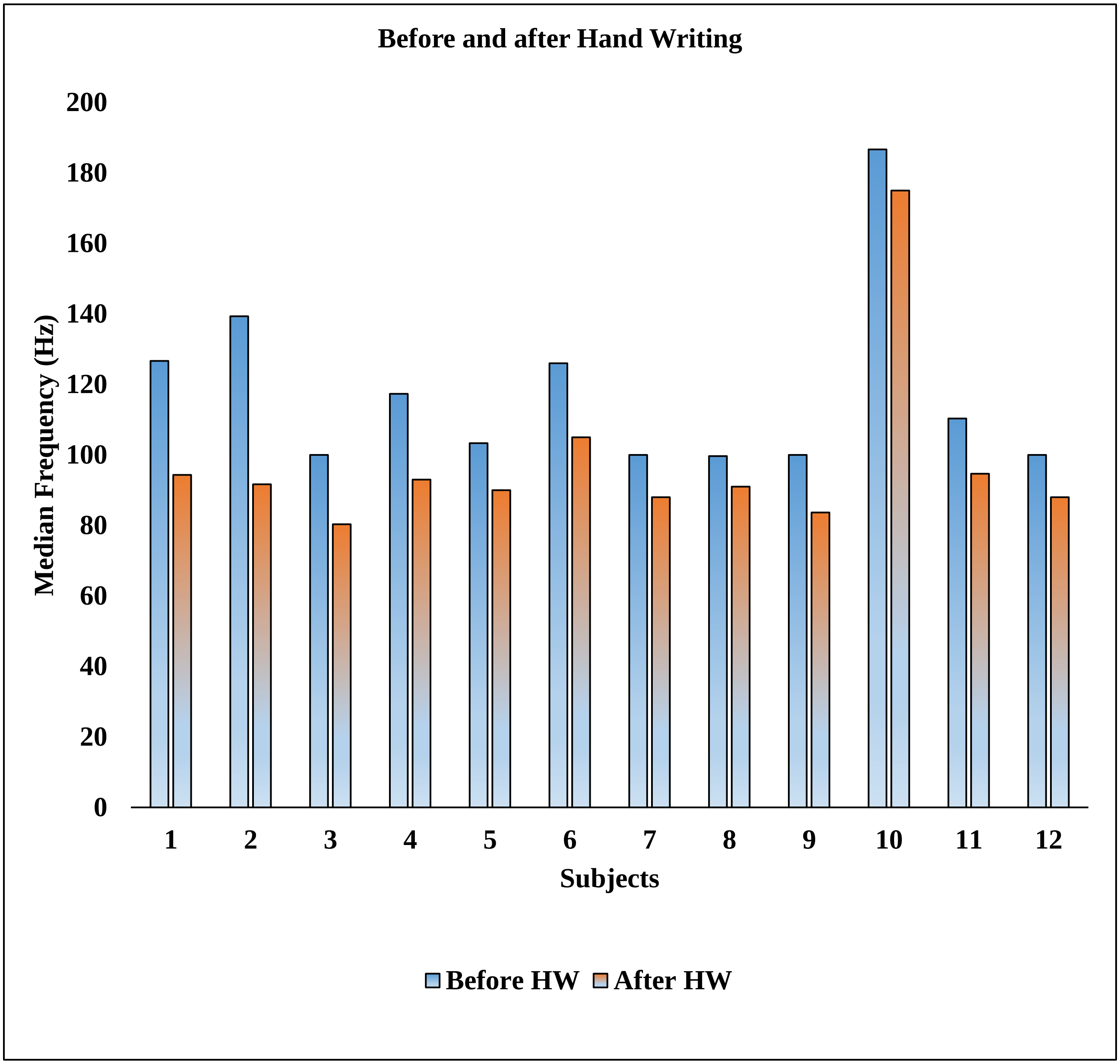


Figure 4: Variation of median frequency for HW task, representing an average of the recorded signal

Table 2: Muscle wise variation of median frequency for HW

Subjects	Flexor Carpi Ulnaris		Flexor Carpi Radialis		Extensor Carpi Radialis	
	Before HW	After HW	Before HW	After HW	Before HW	After HW
1	101	94	181	94	98	95
2	100	95	200	92	118	88
3	132	92	91	75	77	74
4	135	95	117	92	100	92
5	113	103	99	91	98	76
6	140	118	138	101	100	96
7	100	95	100	77	100	92
8	99	91	100	91	100	91
9	98	82	101	86	101	83
10	177	172	201	181	182	172
11	101	87	126	93	104	104
12	100	95	100	92	100	77

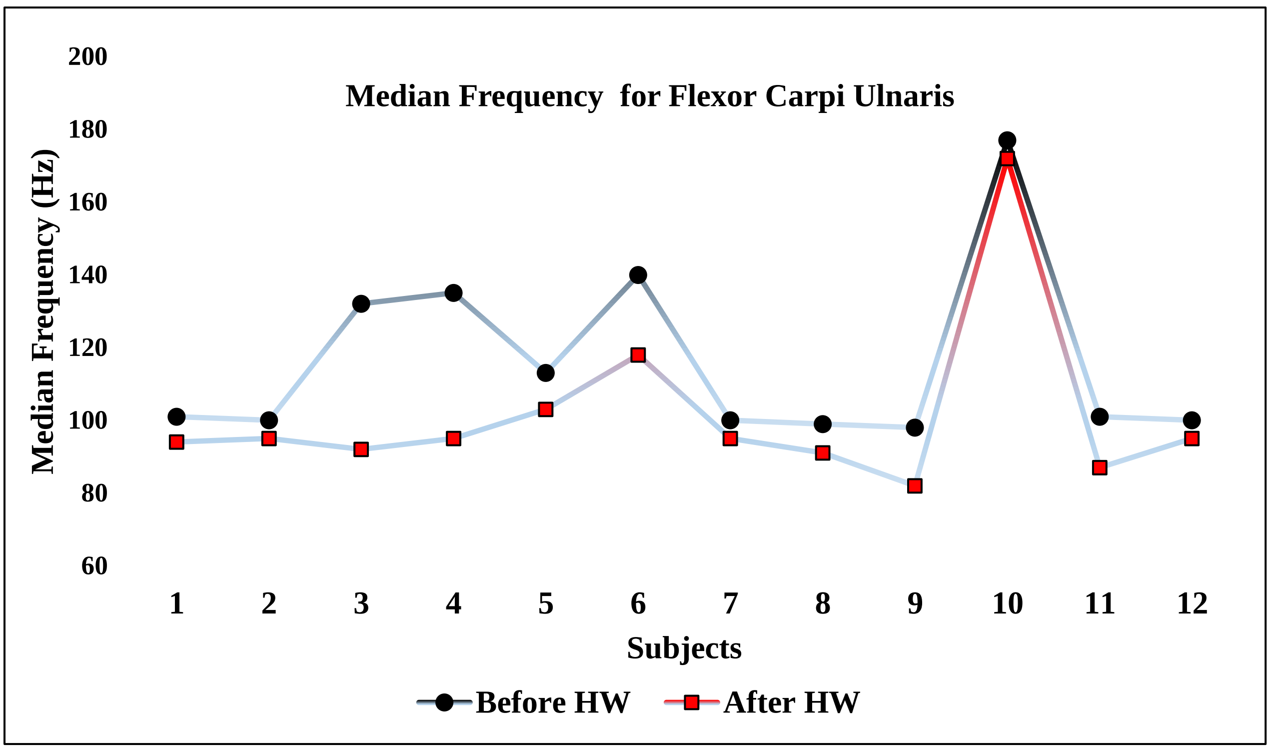


Figure 5: Median frequency for Flexor Carpi Ulnaris muscle before and after HW

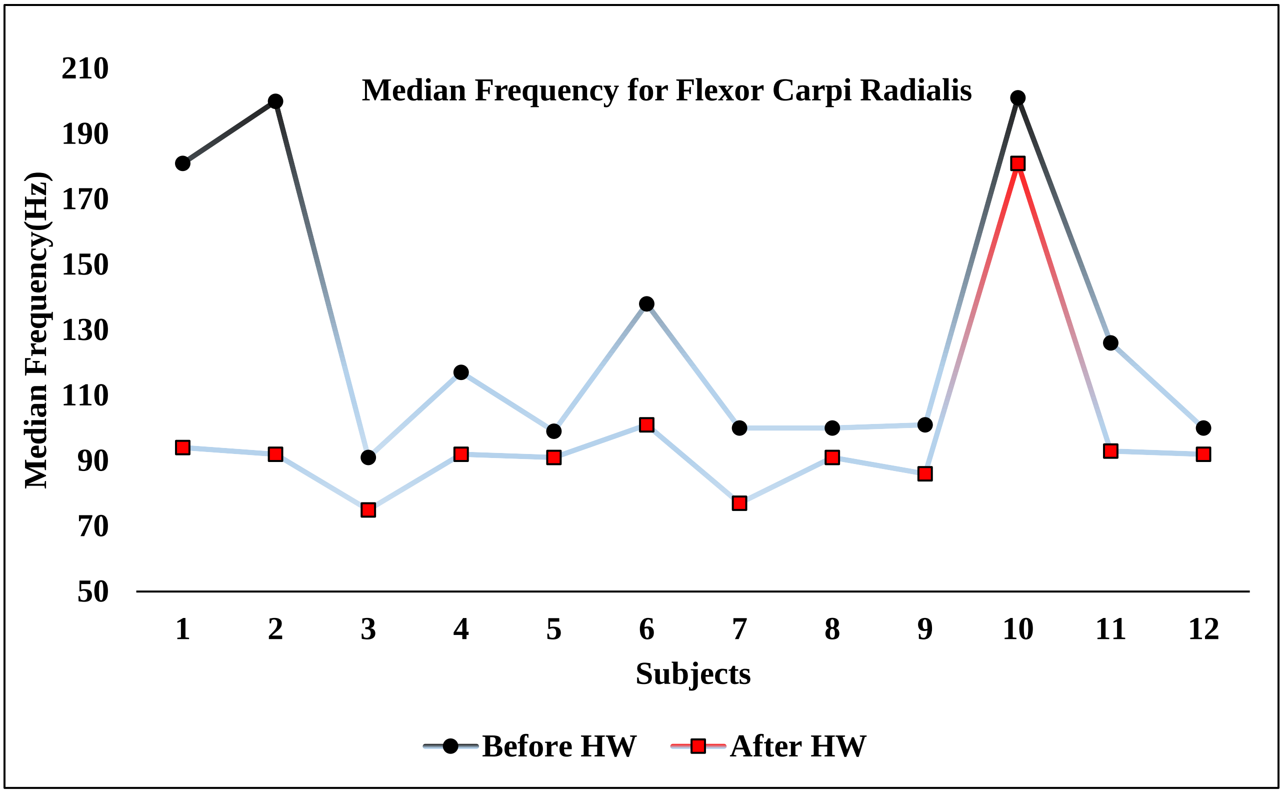


Figure 6: Median frequency for Flexor Carpi Radialis muscle before and after HW

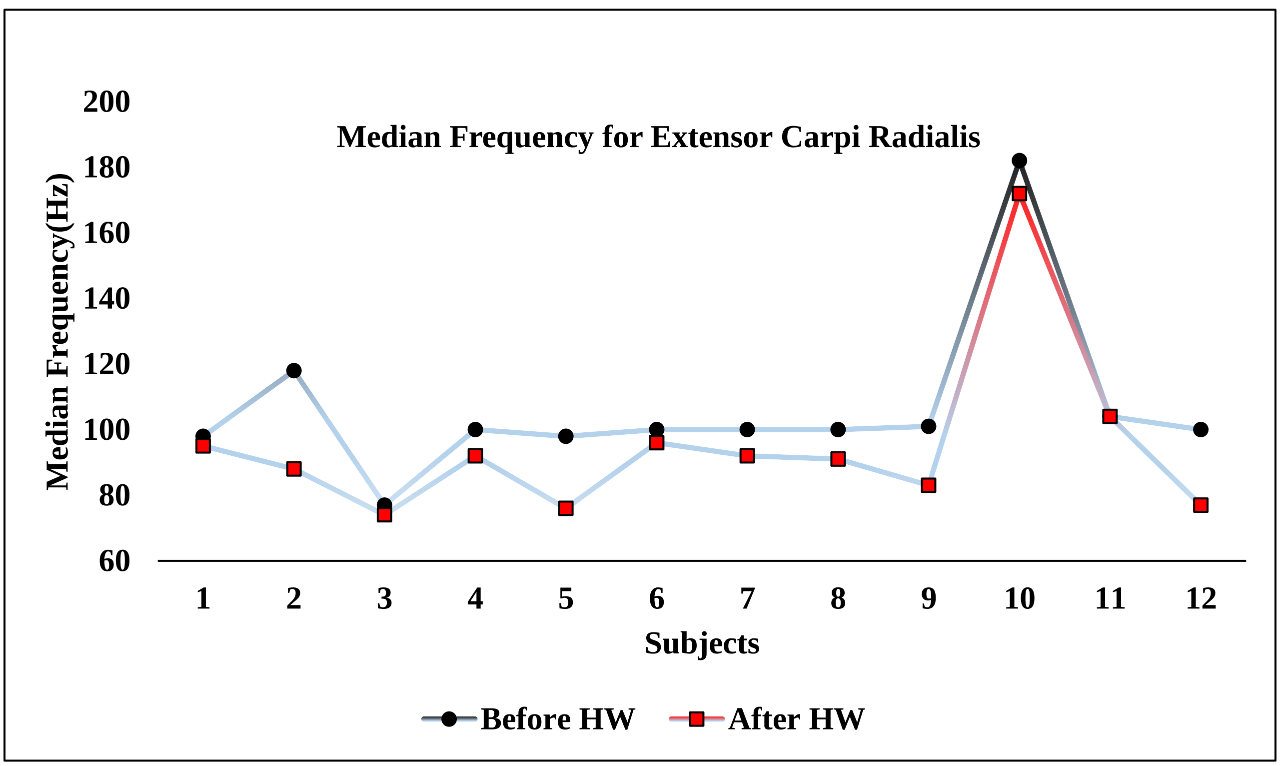


Figure 7: Median frequency for Extensor Carpi Radialis muscle before and after HW

4.2. Median Frequency (Hz) for the Handwriting

The median frequency values for before and after TW task performance are summarized in the following table:

Table 3: Variation of Median Frequency for Typewriting

Subjects	Median Frequency (Hz) Before Typewriting	Median Frequency (Hz) After Typewriting
1	124	98
2	138	99
3	99	95
4	111	102
5	103	99
6	116	97
7	99	98
8	99	99
9	100	100
10	196	190
11	107	100
12	100	101

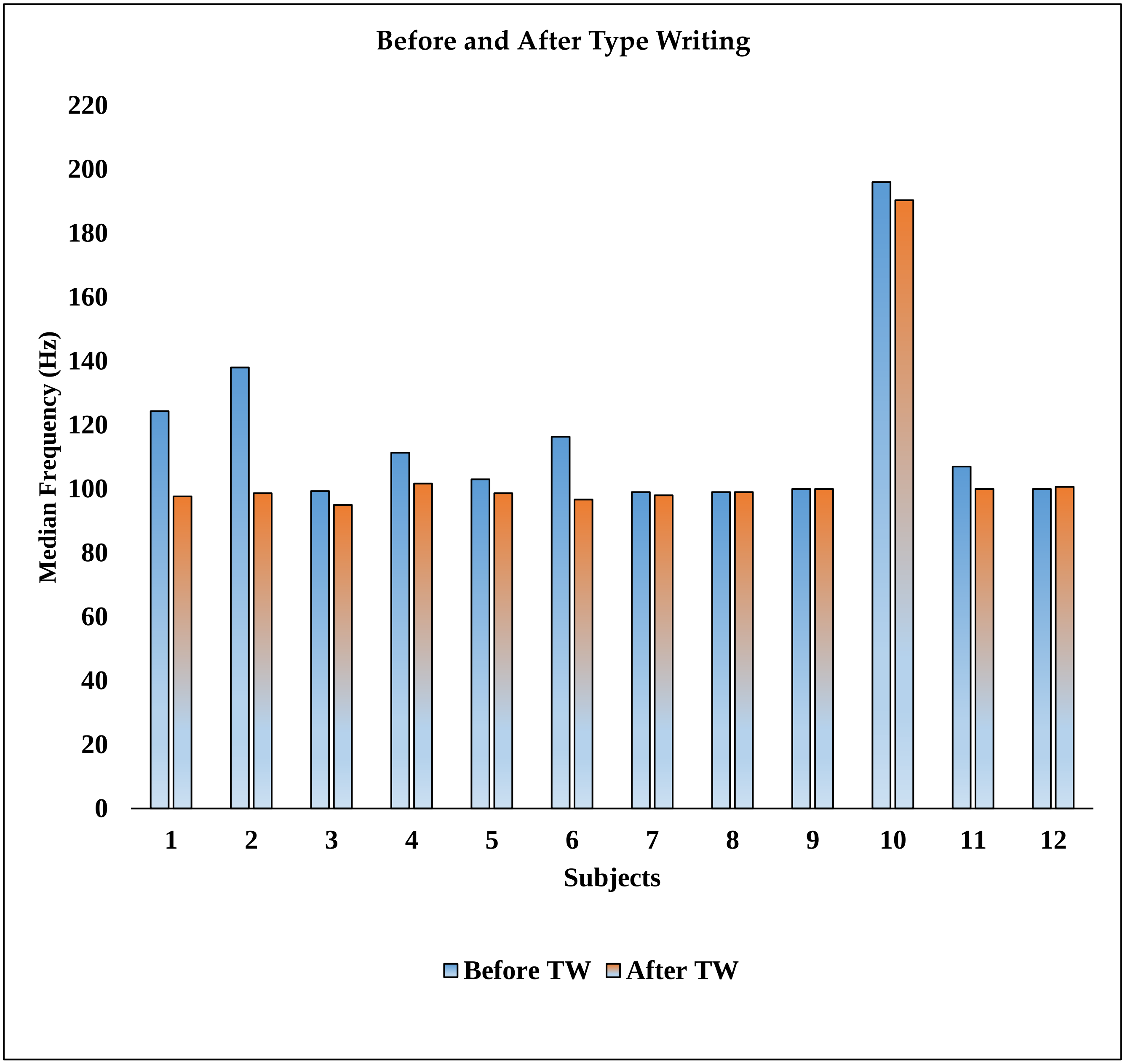


Figure 8: Variation of median frequency for TW task, representing an average of the recorded signal

Table 4: Muscle wise variation of median frequency for TW

Subjects	Flexor Carpi Ulnaris		Flexor Carpi Radialis		Extensor Carpi Radialis	
	Before T. W	After T. W	Before T. W	After T. W	Before T. W	After T. W
1	96	93	177	100	100	100
2	100	101	203	95	111	100
3	127	100	88	85	83	100
4	121	100	113	105	100	100
5	109	103	100	99	100	94
6	133	100	121	100	95	90
7	101	100	101	100	95	94
8	97	95	100	101	100	101
9	100	100	100	100	100	100
10	188	185	200	195	200	191
11	100	100	120	100	101	100
12	100	100	100	102	100	100

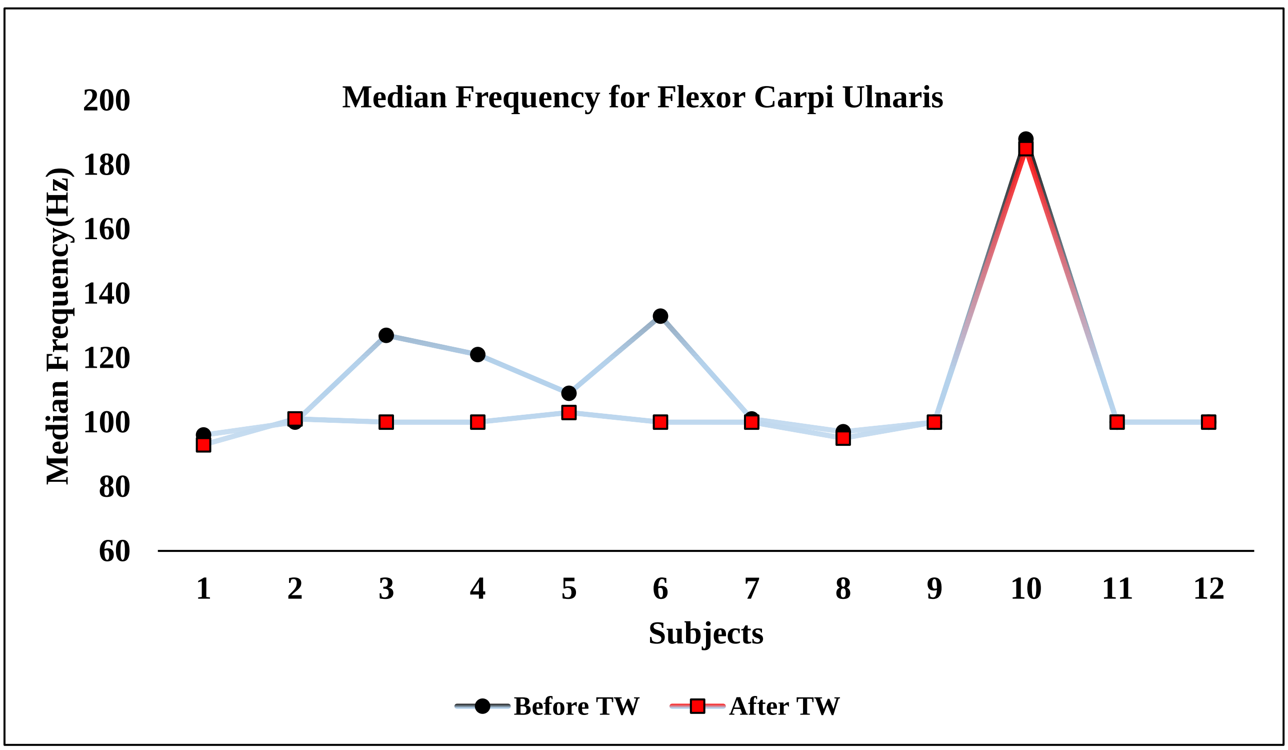


Figure 9: Median frequency for Flexor Carpi Ulnaris muscle before and after TW

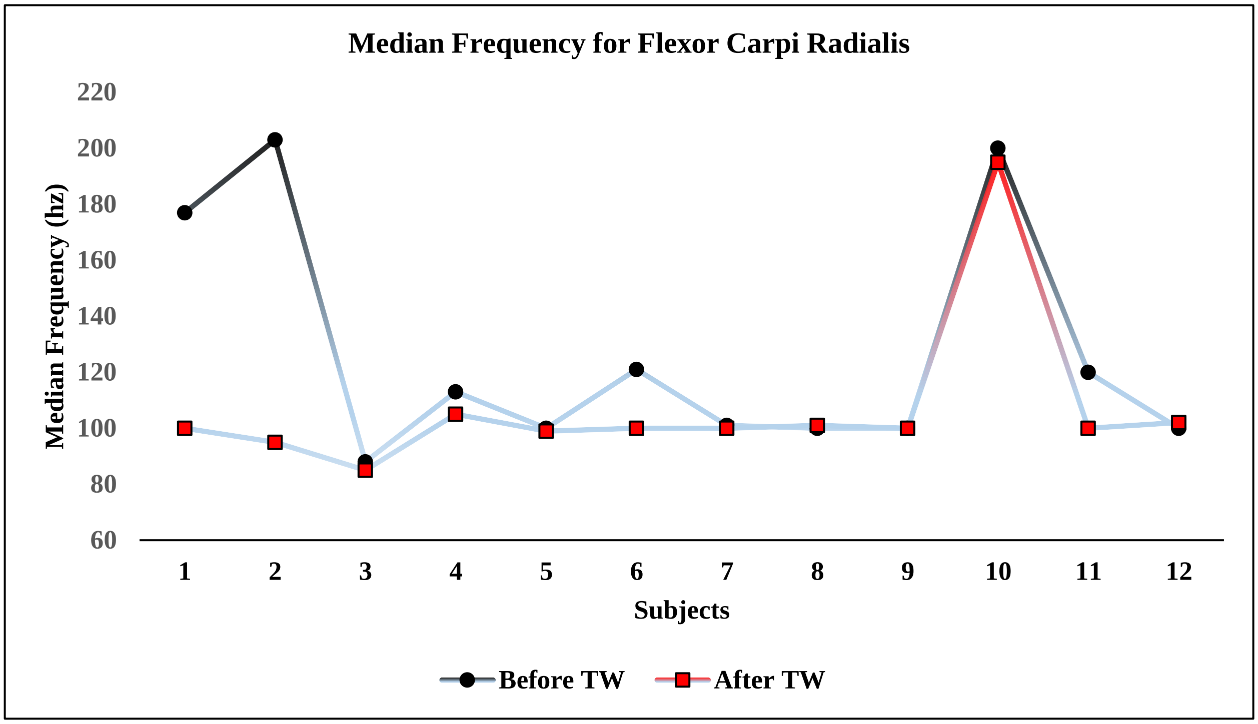


Figure 10: Median frequency for Flexor Carpi Radialis muscle before and after TW

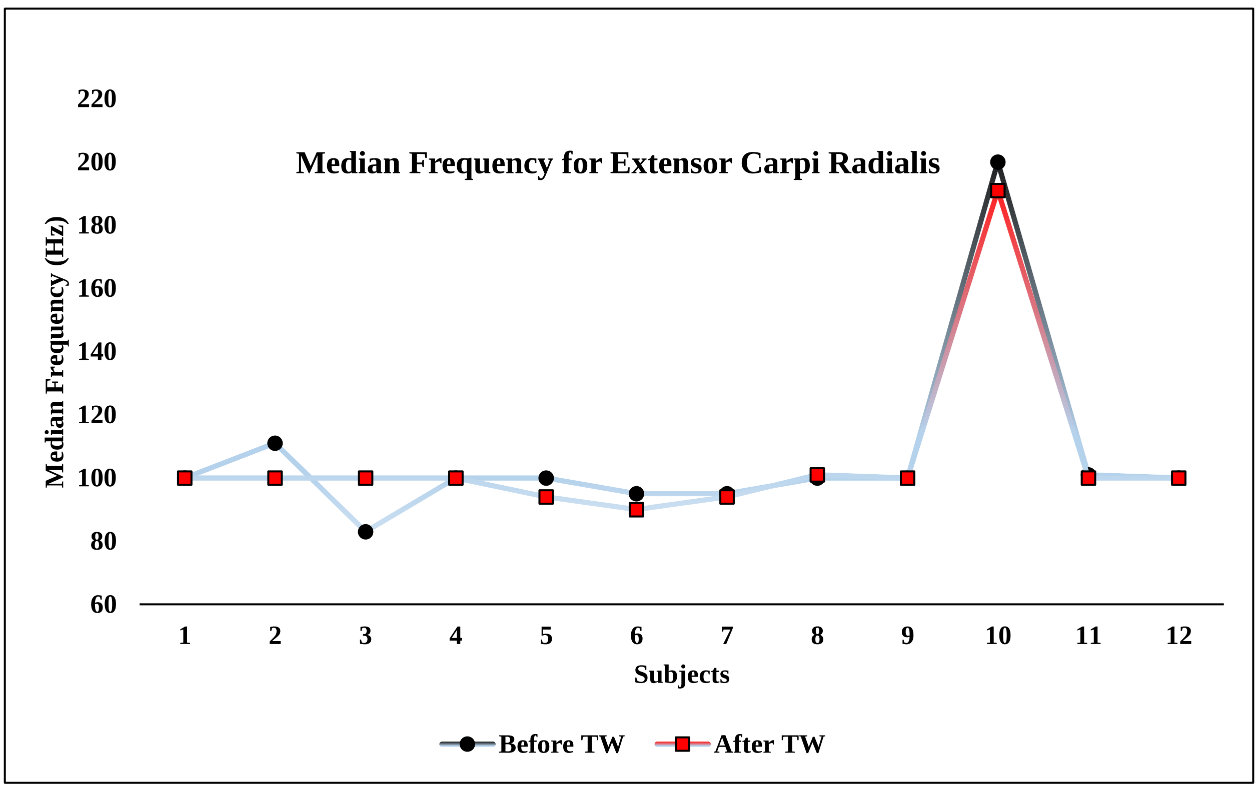


Figure 11: Median frequency for Extensor Carpi Radialis muscle before and after TW

Chapter 5: Discussions

Fatigue is defined as a feeling of tiredness, exhaustion, and a lack of energy that prevents you from doing what you need to do [16]. Physical or mental exhaustion are also possible causes of fatigue [10]. After doing a lot of work, the muscles become tired, and no work can be done, according to research [57]. Muscle fatigue has been shown to decrease executive functioning and cognitive abilities [58]. The goal of this study was to detect local muscular fatigue during handwriting and typewriting task performance, as well as to determine the difference between these two tasks in terms of which task causes greater tiredness: handwriting or typewriting. By measuring the muscle signal using surface electromyography after performing the task by handwriting and typewriting, we were able to distinguish local muscular fatigue in distinct selected muscles (sEMG). In both situations, the reduction in median frequency is clear evidence of increased muscle exhaustion, but more fatigue is identified in handwriting than in typewriting, according to the results.

Muscle fatigue was discovered in many cases in prior investigations, including bicycle runs, playing computer games, muscle fatigue in children with cerebral paralysis, and muscle fatigue as low back pain in bankers. We were able to detect muscle fatigue in the handwriting task in this study, and we came to the conclusion that writing tasks should be shifted to the typewriting system rather than handwriting because the acquired results showed that less fatigue is detected in the typewriting task, and the median frequency remained almost identical after the typewriting task performance.

Many traditional approaches for detecting muscle fatigue have been documented, including zero-crossing rate, wavelet analysis, RMS, and MNF & MDF [59]. Many researchers have demonstrated the usefulness of MNF & MDF as a means of detecting muscle fatigue using surface electromyography, hence it was employed in this investigation. MNF & MDF should be aware of time-varying aspects when determining muscle fatigue. Muscle force and muscle geometry are two parameters that have been linked to muscle fatigue levels [60]. The MDF value was found to be different in some of the patients, with the value increasing rather than decreasing in a few cases. The main reason for the conflict is the skinfold layers of the muscles. Because the EMG scale might be impacted by both of them, the discrepancy in the results could be due to varied muscle fiber composition and distribution [61].

Performing a motor task for an extended amount of time causes muscular fatigue, which results in a reduction in a person's capacity to complete a task [62]. When you're fatigued, the force that propels your muscles to grow weakens, making you feel weaker. If the fatigue is not resolved at that moment, Chronic Fatigue Syndrome (CFS) develops, which is detrimental to one's health [63]. The factors of fatigue induction determine how to treat muscle fatigue. Muscle weakness will usually improve with rest. Maintaining a healthy eating routine will protect you from muscle fatigue and weakness [64].

In the case of handwriting task performance, it has been noted that after a few minutes of writing, a person becomes fatigued due to muscular fatigue [65] and experiences back and shoulder pain, with these complaints being attributed to incorrect pen hold and posture while sitting in a chair for writing [66]. So, to avoid muscular fatigue, a person's pen grip and posture should be right while writing [67], [68].

5.1. Conclusion

The current study's findings demonstrated that after task performance, a decrease in the median frequency of the EMG signal occurs, which is a clear indication of local muscular fatigue developing in all of the selected muscles, and that HW causes more muscle fatigue than TW. Flexor carpi Radialis muscles show a higher level of fatigue than the other muscles in the studies. This could be because Flexor Carpi Radialis muscle involved in the HW task and activated during performance also the flexor carpi Ulnaris and extensor carpi radialis are stronger.

Chapter 6: References

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