

## Investigation of muscle fatigue of the archer's during endurance shooting

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**ABSTRACT** – Endurance of Drawing-Aim-Release (DAR) during the shooting process in archery will be causing the muscles to fatigue. Besides, the archer's inability to use the right muscles for DAR will lead to a muscle injury as well as dropping the performance. This study aims to monitor the localized muscle fatigue of an archer during the repetitive DAR and its effect to the archer's performance. Wet electrode sensors were placed on the specific muscles that are heavily involved in DAR such as Muscle Extensor Digitorum (MED) on the archer's bow arm and the Supraspinatus muscle at the shoulder. In order to induce fatigue, the archer has shot 72 arrows continuously in 2 rounds of set. The surface electromyography (sEMG) signals of the muscle contraction are recorded during the shooting for the post-processing analysis. Each score of the shooting was also recorded to correlate with the effect of muscle fatigue to the archer's performance. The finding of this study is that the MED and Supraspinatus begin to fatigue toward the end of each shooting round. The Root Mean Square (RMS) and Median Frequency (MDF) values for both targeted muscles increased significantly during the 6<sup>th</sup> end compare to the 1<sup>st</sup> end. It is also found that there is no correlation between muscle fatigue on MED and Supraspinatus to the score obtained by the archer where the F value is lower than F-critical while Draw (1.9339), Aim (1.3754) and Release (0.6515) phases. In conclusion, this experiment benefits archers and coaches to identify which muscles are vigorously used during the DAR process and allows for precaution and prevention procedures.

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## INTRODUCTION

Archery shooting techniques can be derived into six phases of movements which are bow hold, drawing, full draw, aiming, release and follow-through [1]. These phases are ideal to be studied in term of motor control and skill obtained during this voluntary kinematic process as they represented a good sequence of movement [1]. However, Mann and Littke [2] simplify these six phases into three which are Drawing-Aiming-Release (DAR) and further defined the archery skill as the aptness to release an arrow to a target within certain time given with high accuracy. Leroyer, Hoecke and Helal [3] stated that the archery phase begins with an archer pushing his/her bow arm which holding the bow, in the direction of the target, while his/her other arm is pulling the string from the beginning of the drawing phase, up until the release is executed. Nishizono et al. [1] explained that in order to achieve the best result, the release phase must be stable and reproducible each and every time.

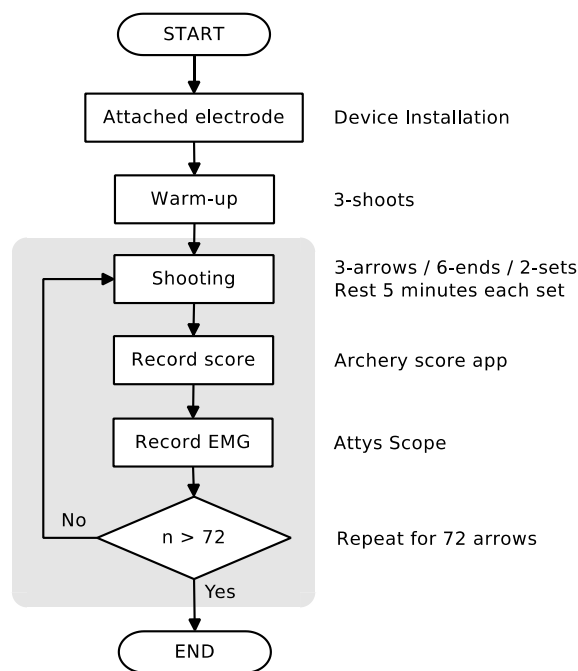
According to a study conducted by Tse et al. [4] repetitive and prolonged activities will lead to muscle fatigue. Over time, the fatigue started to become worse and will most likely lead to injury. In the sport of archery, most of the competitions required archers to shoot around 72 arrows in the qualification round. It means, 72 times of repetitive DAR process during the tournament day, and even more during training phases before the actual competition begins. These repetitive movements contributed the most to injuries in archers, often to their bow arm which is responsible for holding the bow and pushing it in the direction of the target, and the shoulder, which is for drawing the string from the beginning until the release.

A study conducted by Grover and Sinha [6] in India shows that 85 Indian archers were having shoulder pain at the time the survey was conducted, and 67 more archers stated that they were experiencing at least one time shoulder pain in the past. Another survey done by Grover and Sinha [6] was to investigate the impact on current shoulder pain shows that 40% of archers are unable to reach a high score when they are experiencing shoulder pain. It is concluded that the fatigue of the drawing shoulder, especially around supraspinatus affected the archers' performance, leading to their downfall. Another interesting point in this study is that 22% of archers claimed that they are experiencing pain in the bow shoulder, especially during holding the bow. This is most likely due to muscle fatigue that occurred on the forearm due to repetitive movements of the DAR process. This statement is also supported by the research conducted by Ertan [7] about the muscular activation pattern of the bow arm in recurve archery. In this study, he concluded that professional archers rely heavily on MED while holding the bow and pushing them towards the target as the reading of sEMG on this particular muscle is very high before clicking the clicker. However, A. Singh and S. Lhee [8] suggested that excessive stress accumulated on the elbow from holding the bow for too long might also contribute to lateral and medial epicondylitis, which are the sources of the shoulder pain experienced by the archers.

Thus, the aim of this study is to monitor the muscle fatigue around bow arm and shoulder by using sEMG to determine at which point the archers begin to experience the fatigue. Specifically, the present study will examine muscle contraction during endurance archery shooting based on actual competition format. Then, to filter and analyse data obtain from the raw sEMG which can be used to provide correlation between the muscle fatigues and the score achieved at the end of the shooting endurance by using statistical analysis method.

## METHODOLOGY

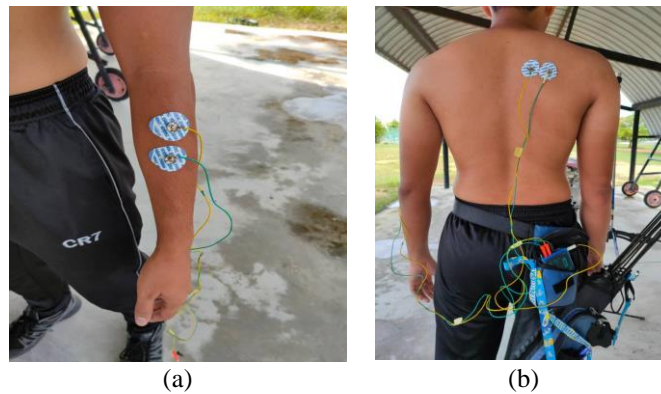
A university archer was selected for this study. The subject is a well-trained recurve archer who has experience participating in various archery tournaments around Malaysia. The summary of the procedure is shown in Figure 1. The flow chart was based on experiment guidelines from researches made by Hayri Ertan [7], Lo [9], Açıkada et al. [10] and Ahmad et al. [11]. However, to induce endurance fatigue, the subject is required to shoot 72 arrows which split into 2 sets (6 Ends per set, 12 Ends in total) within 30 m distance outdoor range, with a certain amount of rest time in between the ends and between the sets. These parameters were added to simulate the actual competition format as close as possible, providing data on what archers are experiencing during the archery competitions.



**Figure 1.** Flow chart of experiment conducted

Firstly, the subject was given time to warm up and sightest shooting for 3 ends. After the sightest finished, surface electrodes were attached on subject 's selected muscles. The skin surface of the selected muscles was prepared by removing hair and rubbing alcohol to reduce signal noise. Since the subject is a right-hand user, surface electrodes that have been connected with Attys (Glasgow Neuro LTD) were attached on the surface of the M. Extensor Digitorum (MED) on left hand and Supraspinatus on right shoulder with 2 cm interelectrodes distance.

MED was selected as Hayri Ertan in his research [7] stated that MED developed an active contraction at the moment they are ready to release the arrow while Nishizono et al. [1] considered MED as the main muscle that is actively involved when an arrow is released towards the target. On the other hand, supraspinatus was chosen because Groover and Sinha [6] highlighted supraspinatus as the fatigued muscle that lead to shoulder injuries among the archers. Plus, research made by Wattanaprakornkul [12] has shown that any movement on shoulder abduction begins with supraspinatus. Thus, it can be concluded that muscle fatigue in Supraspinatus could potentially affect other muscles in the shoulder, which lead to muscles injury. All the wiring that connected the surface electrodes to the Attys were carefully aligned to avoid discomfort for the subject during the shooting process as shown in Figure 2.



**Figure 2.** Surface Electromyography (EMG) electrodes were attached on: (a) MED muscle and (b) supraspinatus muscle

After that, subject was given an opportunity to execute DAR process with six arrows to familiarise the setting configuration on sEMG device and bow. Example of DAR process can be referred in Figure 3.



**Figure 3.** Example of DAR process (a) Draw (b) Aim/Anchor and (c) Release positions

In Attys monitoring setting, high-pass filter, low-pass filter and band-stop filters were set to 10Hz, 50Hz and 60Hz respectively. Since the signal is too small, then it was multiply with maximum gain x1000. A recorder was setup on the right side of the subject, recording the whole experiment so the signal of sEMG can be matched with subject 's body movement in real time as shown in Figure 4.



**Figure 4.** A camera recorder was located opposite to the archer

During the interval for every end, the subject was allowed to rest while the scores recorded by using Archery Score Note apps by Yoshinori Yamanoushi as shown in Figure 5 and prepared for the next end. After six ends, the subject was given 15 minutes to rest, also simulating actual competition format. Then the shooting was repeated until successfully completed 72 arrows.

Meanwhile, the shooting process, all sEMG readings were taken from the subject to be processed and analyzed. The data received by Attys were sent to attys-scope apps in the laptop via Bluetooth connection. At the end of the session, discussions were made about the subject's scores and condition. Any abnormality of scores were highlighted and the subject feedback was response on what happened during that time. The subject was also asked whether physically fatigue, especially on targeted muscles during endurance shooting. The responses were recorded to be made as an explanation of why the subject's EMG reading was inconsistent during the DAR process. Next, the EMG 's data of the subject were filtered and analyzed by using MATLAB.

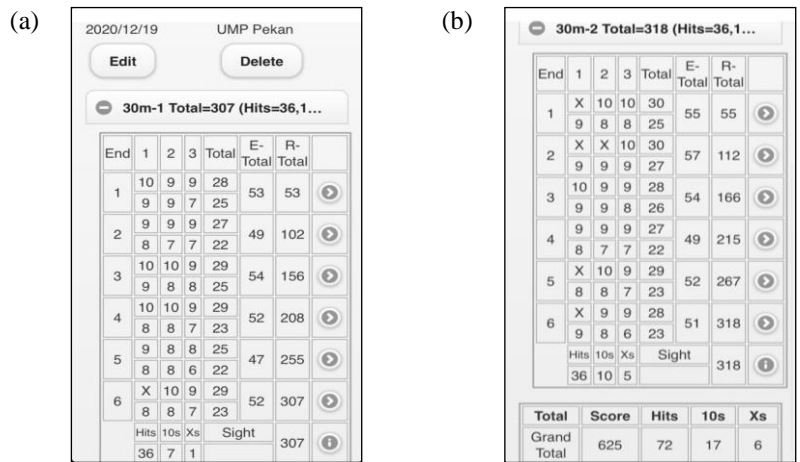


Figure 5. Score for: (a) first set and (b) second set with total score for the session (right)

Statistical analyses such as Root Mean Square (RMS) and Median Frequency (MDF) were used in measuring muscle fatigue conditions, as recommended by Zhou et al. [13], Nur et al. [14], and Ayaz et al. [15], preferred RMS to analyze and interpret the data as RMS calculation gives the best insight on the amplitude of the EMG signal with a waveform that easily be interpreted while Sarker and Mirka [16], Mas’As et al. [17], and Phinyomark et al. [18] preferred MDF as it is frequently considered as the gold standard for muscle fatigue assessment with sEMG signal due to its versatility to analyze both static and dynamic muscle contraction. Alhaag et al. [19], in their recent research, used both RMS and MDF to identify the fatigue associated with different task complexity during maintenance operations while Borges et al. [20] also used these two statistical methods to find the fatigue level of novice and elite archers on flexor digitorum superficialis (FDS). To find the correlation between muscle fatigue and the score obtained by the subject, several methods such as t-test, f-test, and Analysis of Variance (ANOVA) can be used to achieve the objective. Hairi Ertan in his research [7] determined the correlation between MED and M. Flexor Digitorum Superficialis (MFDS) with the score obtained by the subjects in his research by using the ANOVA method. The correlation between muscle fatigue experienced by the subject and the score obtained at the end of endurance shooting session was found by using ANOVA analysis with 95% of confidence interval.

RESULTS AND DISCUSSION

Figure 6 shows the score comparison between each end for both sets. In the first set (grey bar), the highest score obtained by the subject is 53 on the 1<sup>st</sup> end, while the lowest is 47 on the 5<sup>th</sup> ends. On the 2<sup>nd</sup> set (red bar), the highest is 57 on the 8<sup>th</sup> ends, while the lowest is 49 on the 4<sup>th</sup> ends. The total score for both sets are 307 and 318 respectively. Interestingly, the lowest score obtained by the subject happened at the last three Ends for both sets, indicating a possible muscles fatigue on both MED and Supraspinatus.

By analyzing the signal from sEMG on both targeted muscle via MATLAB, generally, the signal transmitted by M. Extensor Digitorum and Supraspinatus are shown in Figure 7. All of these signals were analyzed by matching the action of the subject at a certain time with the video that has been recorded as mentioned earlier to classify the DAR process. Obviously, the highest value of EMG was represent the drawing activity when it needs to pull the string arrow to the maximum drawlength. Also, the significant muscle contributes by the supraspinatus compared to the MED. During aiming process, the lowest muscle contraction appeared for both muscles due to locking position and just waiting to release an arrow. Finally, when arrow is releasing, the MED is took place to hold the bow to maintain position and prevent from vibration. Therefore, it have small contraction by MED during release activity.

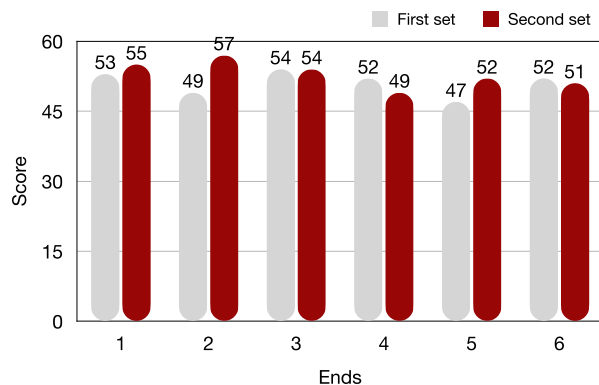
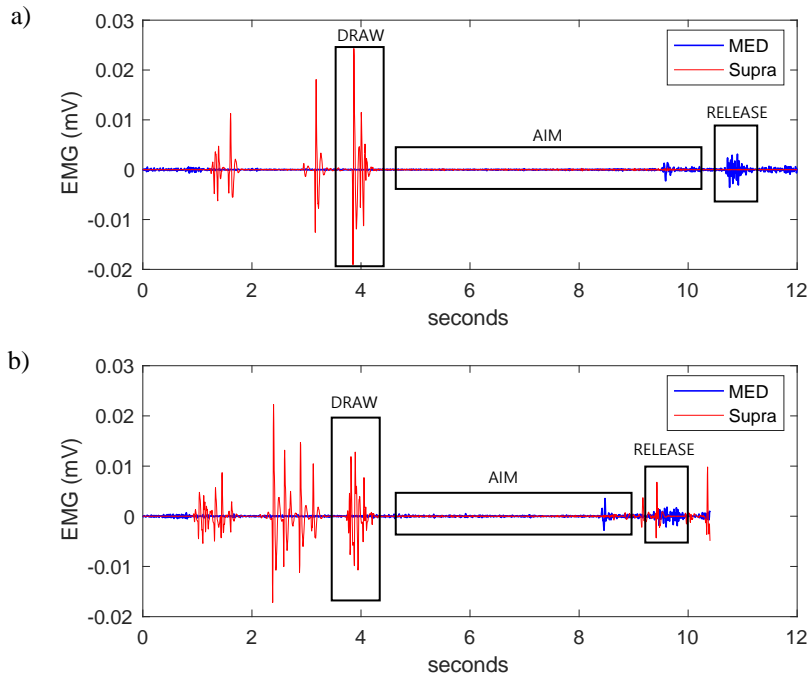


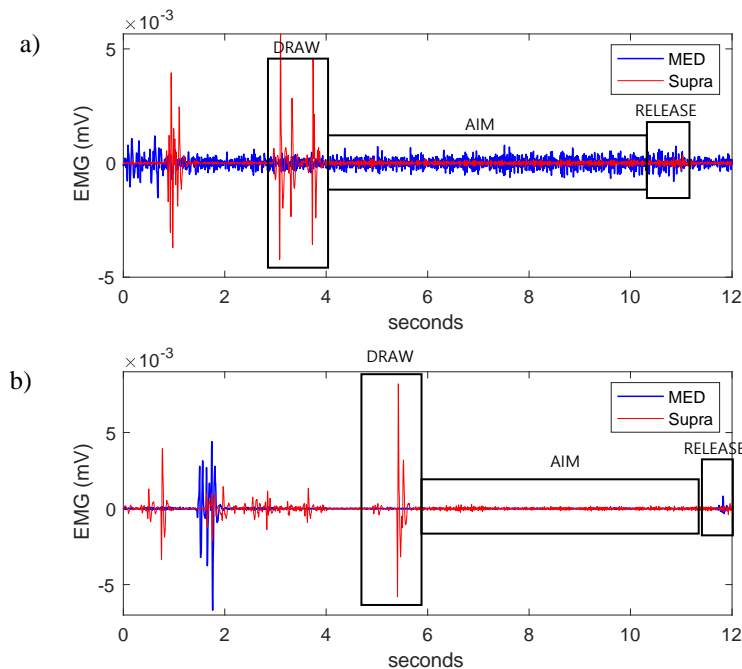
Figure 6. Score comparison between 1<sup>st</sup> set and 2<sup>nd</sup> set for each end



**Figure 7.** Signal transmitted by sEMG for MED and Supraspinatus 1<sup>st</sup> set at (a) first end (b) sixth ends

As the bow jump to finger sling (a device that securely places the bow to archer’s hand, to avoid the bow from falling), right after the release and follow-through, the MED was strained to dampen the process, allowing for a quick recovery for the next shot, thus explaining why there is a noticeable sEMG signal on MED during release process on both ends. Another interesting piece of data that we can point out is that the overall sEMG reading between the 1<sup>st</sup> end and 6<sup>th</sup> end is almost consistent, thus explaining the only small difference in score on 1<sup>st</sup> end (53/60) and 6<sup>th</sup> end (52/60).

In Figure 8, which covered the 1<sup>st</sup> and 6<sup>th</sup> end for the 2<sup>nd</sup> set, we could see clearly that the value of sEMG is smaller compared to data in Figure 7 due to fatigue that occurred on both muscles. Plus, in Figure 8(a), the reading of MED is higher in Aim phase, compared to Supraspinatus, as opposed to the previous figure, showing that the subject was unable to balance both muscles during the extension process. In Figure 8(b), the reading of the sEMG signal becomes incoherent compared to Figure 8(a) and Figure 7, indicating that total fatigue has kicked into the subject. It also explained the score gap between the 1<sup>st</sup> end (55/60) and the 6<sup>th</sup> end (51/60) during the 2<sup>nd</sup> set of endurance shooting. The gap might be small at one glance, however, in the competition, inconsistency of total scores for each end might affect archers' ranking, denying their chances to be placed at the top seed.



**Figure 8.** Signal transmitted by sEMG for MED and Supraspinatus 2<sup>nd</sup> set at (a) first end (b) sixth ends



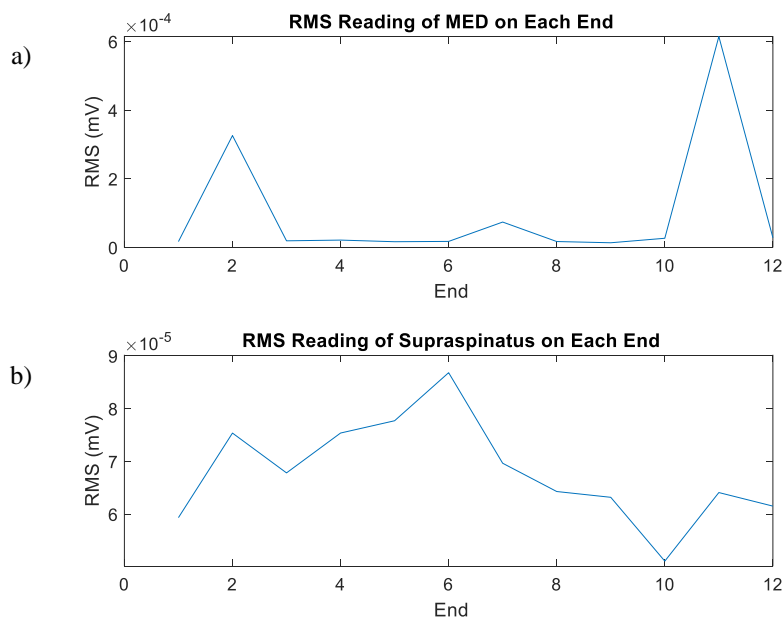
The signals from MED and Supraspinatus were recorded every time the subject shoots an arrow, which mean there are 72 signals at the end of the session. All of these signals were analyzed by matching the action of the subject at certain time with the video that has been recorded as mention earlier to determine DAR process. In Figure 8, the setup and draw movement caused high reading of sEMG at both muscles. However, the reading on both muscles were toned down and become almost constant during anchor, aim and expand. Then, the reading spiked again during release process indicating that there are major movement in both targeted muscles during this process.

Next, to identify whether the targeted muscles experience fatigue or not during the shooting process, the subject was asked about which phase was the hardest to execute. The subject's answer was the Aim process, which required the subject to aim onto the target using the left arm while simultaneously expanding his back tension on right shoulder to execute the whole process as clean as possible. During the experiment, there were several times, especially toward the end of every set where the subject was unable to maintain the Aim process, forcing him to reset the DAR process and started again. Thus, by observing the RMS and MDF value in both MED and Supraspinatus during the Aim process will give a clue of what happened to these muscles during this phase.

**Table 1.** Average RMS and MDF values of MED and Supraspinatus from 1<sup>st</sup> End to 12<sup>th</sup> End during Aim process

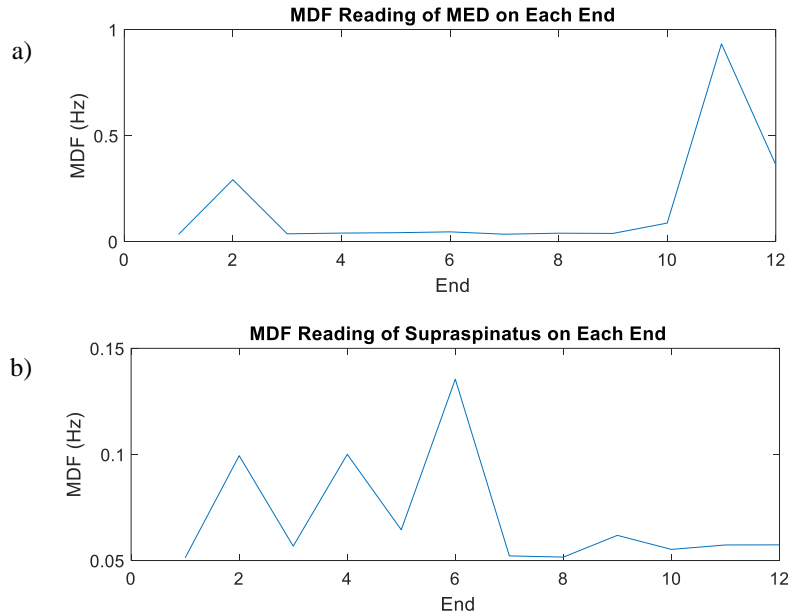
Set	Ends	MED <sub>RMS</sub>	Supra <sub>RMS</sub>	MED <sub>MDF</sub>	Supra <sub>MDF</sub>
1	1	1.73E-05	5.93E-05	3.40E-02	5.12E-02
	2	3.26E-04	7.54E-05	2.92E-01	9.94E-02
	3	1.95E-05	6.78E-05	3.65E-02	5.68E-02
	4	2.16E-05	7.54E-05	4.00E-02	1.00E-01
	5	1.69E-05	7.77E-05	4.18E-02	6.45E-02
	6	1.78E-05	8.68E-05	4.58E-02	1.35E-01
2	7	7.42E-05	6.97E-05	3.48E-02	5.22E-02
	8	1.74E-05	6.43E-05	3.95E-02	5.16E-02
	9	1.38E-05	6.32E-05	3.84E-02	6.19E-02
	10	2.69E-05	5.11E-05	8.72E-02	5.52E-02
	11	6.15E-04	6.41E-05	9.33E-01	5.73E-02
	12	2.86E-05	6.15E-05	3.62E-01	5.74E-02

On one hand, it is widely accepted that the increased value of RMS during muscle contraction indicates that the muscles are experiencing fatigue from the load induced [14], [15]. In Table 1, the RMS of MED increased from 1.73E-05 at 1<sup>st</sup> end to 2.86E-05 at 12<sup>th</sup> end, whereas the RMS for Supraspinatus increased from 5.93E-05 at 1<sup>st</sup> end to 6.15E-05 12<sup>th</sup> end. Despite the RMS value being smaller compared to the data obtained by Borges et al.[20], and Ertan [7], the increased value of RMS from 1<sup>st</sup> end to 12<sup>th</sup> end on both MED and Supraspinatus proved that the muscles were in the fatigue condition by the end of the endurance shooting session. That being said, there are moments where the subject managed to control the fatigue during the experiment, as shown in Figure 9 where the RMS value on both muscles decreased at certain ends.



**Figure 9.** Graph of RMS reading from 1<sup>st</sup> End to 12<sup>th</sup> End for (a) MED and (b) Supraspinatus

On the other hand, most researchers agreed that a decreased value of MDF on a muscles contraction shows that the muscles are experiencing fatigue [16-18]. In Table 1, there are several moments where the subject begins to experience fatigue on Supraspinatus such as during the 5<sup>th</sup> end where the MDF value drop significantly to 6.45E-02 compared to 1.00E-01 on the 4<sup>th</sup> end at Supraspinatus. On MED, however, the fatigue becomes obvious during the 8<sup>th</sup> end (3.95E-02) compared to the 6<sup>th</sup> end (4.58E-02). The increased value of MDF on certain ends as shown in Figure 10 for both muscles also show that the subject managed to recover from the fatigue during the endurance shooting session, albeit a little. These discoveries tallied with the results made by Borges et al. [20], where the RMS and MDF reading on both novice and elite archers are sometimes decreased and increased respectively at certain Ends, indicates that they managed to control the muscles properly to ensure their best performance is maintained despite under fatigue condition.



**Figure 10.** Graph of MDF reading from 1<sup>st</sup> End to 12<sup>th</sup> End for (a) MED and (b) Supraspinatus

During the Aim phase, the subject had to micromanage the MED to carefully aim the sight pin to the target, while holding the weight of the bow and the stabilizers. The subject also had to maintain the tension on Supraspinatus during anchor to ensure a smooth and clean release of the arrow. When these multiple tasks are done repetitively, it becomes the source of muscles fatigue that the subject experienced during the endurance shooting session. Another important discovery from Table 1 shows that there is a very weak correlation between the RMS MED and RMS Supraspinatus (0.00867), and between MDF of MED and MDF of Supraspinatus (0.107) by using a correlation test from Excel. This means that despite MED and Supraspinatus are simultaneously contracted during the aim phase. Both muscles experience a different pace of fatigue and recovery, thus, explaining why sometimes the RMS of MED is increasing whereas the RMS of Supraspinatus is decreasing at the same end. Comparing to the previous end, and vice versa on MDF for both muscles in Table 1.

Next, Two-Way ANOVA is used to find the correlation between the fatigue experienced by both muscles, and the score obtained by the subject from 1<sup>st</sup> end to 12<sup>th</sup> end during DAR phases. Table 2 shows that there is no correlation between muscle fatigue that happened on both MED and Supraspinatus and the score obtained by the subject for both sets as the F value is lower than Fcritical (2.8387). Value of F for each Draw is 1.9339, Aim 1.3754 and Release 0.6515 phases. It is accepting the null hypothesis which is there is no interaction between RMS and MDF for MED and Supraspinatus.

**Table 2.** Summary output of correlation between DAR process on MED and Supraspinatus for overall endurance shooting session using ANOVA

Phase	Interaction Statistic		
	F	F-Crit	P-value
Draw	1.9339	2.8387	0.1396
Aim	1.3754	2.8387	0.2642
Release	0.6515	2.8387	0.5867

These results show that even though fatigue occurred on both muscles toward the end of every set, it only has minimum effect on scores obtained by the subject. Other factors such as presence of wind, type of equipment used and total amount of training per week might have greater effect to the scores on each set. That being said, if the subject shoots another 72

arrows during the experiment, the correlation between muscle fatigue on both targeted muscles and the score obtained may exist.

## CONCLUSION

In conclusion, EMG signals, RMS and MDF show that the subject does experience muscle fatigues on both MED and Supraspinatus. However, it does not affect the score obtained by the subject at the of both sessions, as the subject managed to control the fatigue properly and was able to execute the DAR phase as consistent as possible, and the fact that the score for the 2<sup>nd</sup> set is higher compared to the 1<sup>st</sup> set. It is recommended that in the future, new parameters must be added in the endurance shooting session such as the heart rate to induce the high-stress conditions. Moreover, several intensities should be considered restricting arrow release time, increasing the number of arrows and some physical activity before shooting such as jumping or running.

Muscle fatigues without necessary treatment, will lead to muscle injuries. Without proper training, enough rest and balanced eating of nutritious foods, the muscle fatigue on MED and Supraspinatus will recover at a very slow rate and led to reduce the archers' performance. This study is completed to give awareness to coaches and athletes about the limitations of our bodies in handling a high volume of exercise. Also, importance of systematic training schedules to bring out the full potential of athletes and preventing injuries.

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