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Effects of shoulder manipulation on electromyography measures in archery athletes during recovery from fatigue: a comparison between sexes

Efectos de la manipulación del hombro en las medidas de electromiografía en atletas de tiro con arco durante la recuperación de la fatiga: una comparación entre sexos

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Abstract. The aim of this study was to analyze the effects of manual therapy on electromyography (EMG) measures of the primary muscles involved in archery, considering the differences between sexes. Twenty trained archery athletes (men: 14, age: 32.1±6.6 years; women: 6, age: 25.3±5.0 years) participated in this experimental study. The athletes were subjected to 100 archery shots, after which they received regenerative manual therapy. EMG measurements were taken from the middle deltoid, posterior deltoid, upper trapezius, middle trapezius, lower trapezius, and infraspinatus muscles before the shots, after the shots, and after the manual therapy. The outcomes measured included the mean and maximal amplitude of the EMG root mean square (EMG_{RMS}) and the median frequency of the raw surface EMG signal power spectrum (EMG_{MED}). Sex comparisons revealed a significantly higher EMG_{MED} in the upper trapezius following manual therapy in women compared to men (F=5.096; p=0.037). No other significant differences were found between sexes (p>0.05). Repeated measures conducted at baseline, after 100 shots, and after manual therapy showed a significantly greater mean amplitude EMG_{RMS} in the infraspinatus following manual therapy compared to after 100 shots (169.7 vs. 109.8 µV; p=0.008). Similar results were noted for maximal amplitude EMG_{RMS} (372.7 vs. 209.5 µV; p=0.010). Additionally, a significantly lower maximal amplitude EMG_{RMS} was observed at baseline compared to after manual therapy in low trapezius (312.6 vs. 551.2 µV; p=0.045). In summary, and overall, manual therapy did not play a significant role in restoring the EMG parameters in the primary muscles of archers after exposure to a fatigue condition. However, it showed efficacy in the case of the infraspinatus. Furthermore, apart from the upper trapezius, no significant effects were observed between genders, indicating similar effects in both.
Keywords: archery; muscle fatigue; recovery; physical therapy modalities.

Resumen. El objetivo de este estudio fue analizar los efectos de la terapia manual en las medidas de electromiografía (EMG) de los músculos primarios involucrados en el tiro con arco, considerando las diferencias entre sexos. Veinte atletas entrenados de tiro con arco (hombres: 14, edad: 32.1±6.6 años; mujeres: 6, edad: 25.3±5.0 años) participaron en este estudio experimental. Los atletas realizaron 100 disparos de tiro con arco, después de lo cual recibieron terapia manual regenerativa. Se tomaron medidas de EMG del deltoides medio, deltoides posterior, trapecio superior, trapecio medio, trapecio inferior y músculo infraespinoso antes de los disparos, después de los disparos y después de la terapia manual. Los resultados medidos incluyeron la amplitud media y máxima del valor cuadrático medio de la EMG (EMGRMS) y la frecuencia mediana del espectro de potencia de la señal EMG de superficie cruda (EMGMED). Las comparaciones entre sexos revelaron una EMGMED significativamente mayor en el trapecio superior después de la terapia manual en mujeres en comparación con hombres (F=5.096; p=0.037). No se encontraron otras diferencias significativas entre sexos (p>0.05). Las mediciones repetidas realizadas en la línea de base, después de 100 disparos y después de la terapia manual mostraron una amplitud media EMGRMS significativamente mayor en el infraespinoso después de la terapia manual en comparación con después de 100 disparos (169.7 vs. 109.8 µV; p=0.008). Se observaron resultados similares para la amplitud máxima EMGRMS (372.7 vs. 209.5 µV; p=0.010). Además, se observó una amplitud máxima EMGRMS significativamente menor en la línea de base en comparación con después de la terapia manual en el trapecio inferior (312.6 vs. 551.2 µV; p=0.045). En resumen, y en general, la terapia manual no jugó un papel significativo en la restauración de los parámetros de EMG en los músculos primarios de los arqueros después de la exposición a una condición de fatiga. Sin embargo, mostró eficacia en el caso del infraespinoso. Además, aparte del trapecio superior, no se observaron efectos significativos entre sexos, lo que indica efectos similares en ambos.
Palabras clave: tiro con arco; fatiga muscular; recuperación; modalidades de terapia física.

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Introduction

The primary action in archery involves drawing the bowstring, aiming, and releasing the arrow, which engages several muscle groups (Ertan, 2009; Ertan et al., 2003). The key muscles utilized include the deltoids and rotator cuff muscles (e.g., supraspinatus, infraspinatus, teres minor, and subscapularis) in the shoulder, which are critical for stabilizing and controlling the bow (Sládek et al., 2022). The trapezius in the back provides the power to draw the bowstring (Sládek et al., 2022). The precise coordination and sustained muscle contractions required in archery also demand significant endurance, particularly in the upper body and core, to maintain accuracy and consistency over prolonged periods (Chen et al., 2023).

Repetitive shooting during archery training can impact athletes' ability to maintain performance due to muscular fatigue (Hamdan et al., 2022). This fatigue may increase the likelihood of performance decline and compromises overall movement control due to reduced muscular support (Dorshorst et al., 2022). For example, muscle endurance has been linked to improved performance in archery, supporting the idea that the ability to endure muscular fatigue in repetitive conditions is a key physical factor for archery athletes (Saleh et al., 2022).

Electromyographic (EMG) activity of the key muscles as

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trapezius, posterior and middle deltoids, and infraspinatus muscles is critical in understanding the muscular activity of archers (Ibrahim & Abdelgawad, 2024). It is expected that during repetitive archery shots, measures as the mean and maximal amplitude of the EMG root mean square (EMG_{RMS}) in these muscles tend to increase, reflecting higher muscle activation and fatigue over time (Ibrahim & Abdelgawad, 2024). Specifically, the trapezius and deltoid muscles may show significant EMG_{RMS} increases due to their role in shoulder stabilization and upper limb movement (Wiker et al., 1989). Additionally, the median frequency of the raw surface EMG signal power spectrum (EMG_{MED}) may decrease with repetitive shooting due to muscle fatigue (Borges et al., 2020), as the power spectrum shifts towards lower frequencies due to the recruitment of slower-twitch muscle fibers and a decrease in conduction velocity (De Luca, 1997).

Manual therapy can significantly improve EMG parameters following muscle fatigue (Daneau et al., 2019), promoting recovery and potentially minimizing injury risk (Avandi et al., 2024; Short et al., 2023). Manual therapy techniques, such as massage (Weerapong et al., 2005), myofascial release (Mauntel et al., 2014), or joint mobilization (Hanrahan et al., 2005), can enhance muscle function by reducing muscle tension, improving blood flow (Kaharina et al., 2024; Nugroho et al., 2024). These effects contribute to a quicker reduction in muscle fatigue (Weerapong et al., 2005). By alleviating muscle fatigue and restoring optimal muscle function, manual therapy may help in maintaining muscle health and mainly restoring the recovery of the EMG parameters after muscle fatigue (Ghasemi et al., 2020), thereby reducing the risk of overuse injuries and promoting overall musculoskeletal resilience.

However, the effectiveness of manual therapy in restoring EMG parameters after muscle fatigue may depend on the sex of archery athletes due to physiological and biomechanical differences (George et al., 2007). Sex-specific factors such as muscle mass, fiber composition, hormonal influences, and pain perception can influence how muscles respond to both fatigue and recovery interventions (Avin et al., 2010). Men generally have a higher proportion of fast-twitch muscle fibers, which fatigue more quickly but also recover faster with appropriate interventions like manual therapy (Hottenrott et al., 2021). Females, on the other hand, tend to have a higher proportion of slow-twitch fibers, greater pain tolerance, and different hormonal profiles that can affect muscle recovery dynamics since estrogen can reduce muscle inflammation and damage after exercise, leading to faster recovery (Tiller et al., 2021). These factors may result in a slower yet sustained improvement in EMG parameters, with potential variations in how manual therapy techniques need to be applied for optimal effectiveness (Crow et al., 2011).

The deltoids, trapezius and rotator cuff muscles (e.g., supraspinatus, infraspinatus) are crucial in archery as they stabilize and control the bow, directly impacting accuracy and endurance (Sládek et al., 2022). During prolonged shooting sessions, these muscles are susceptible to fatigue, which can compromise the archer's stability, precision, and overall performance. Research shows that muscle fatigue affects males and females differently due to variations in muscle fiber composition, hormonal influences, and physical conditioning (Tiller et al., 2021). Males typically exhibit greater muscle mass and strength, while females often display greater resistance to fatigue, possibly due to higher percentages of Type I muscle fibers and differences in neuromuscular activation. However, the exact implications of these differences on archery performance remain underexplored. Therefore, it is critical to investigate the efficacy of manual therapy in restoring muscle functionality in both sexes after fatigue. Understanding sex-specific responses to fatigue and recovery interventions could lead to more tailored and effective treatment protocols, enhancing performance and reducing the risk of injury in male and female archers alike. Better understanding the consequences of muscle fatigue and the impact of manual therapy can provide valuable guidance for physiotherapists and coaches working with archery athletes, enabling them to adopt individualized recovery strategies after high volumes of repeated shots and longer training sessions. Based on these considerations, the purpose of this study was to analyze the effects of manual therapy on EMG measures of the primary muscles involved in archery, taking into account the differences between sexes.

Methods

This study followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines (Cuschieri, 2019). The Independent Bioethics Committee for Scientific Research at the Medical University of Gdańsk approved this study on December 14, 2023 (Resolution No. KB/750/2023-2024). Participants were thoroughly informed about the study, including a simplified overview of the protocol. They provided written informed consent prior to participation, acknowledging their voluntary involvement and their right to withdraw from the study at any time without any consequences. The study followed the ethical guidelines set forth in the Declaration of Helsinki (World Medical Association, 2013).

Study design

This study was a non-randomized and non-controlled experimental design involving twenty archery athletes. There was a total of twenty archers (14 men and 6 women). EMG measurements were taken at baseline, after 100 shots of archery, and following exposure to manual therapy. EMG measurements were taken from the middle deltoid, posterior deltoid, upper trapezius, middle trapezius, lower trapezius, and infraspinatus muscles.

Setting

The evaluation and experimental intervention took place at the archers' training facility around the end of 2023

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and the beginning of 2024. The initial assessment was conducted on a training day, immediately after the athletes' warm-up and just before the session began. The second assessment was carried out five minutes after the athletes completed 100 archery shots, and the third assessment was performed following the manual therapy. Each player was individually evaluated in the afternoon (approximately 4 pm) after 48 hours of rest. A convenience sampling method was used, inviting experienced archers from the regional club. Recruitment was done through club announcements and social media posts.

Participants

The sample size for the study was determined using G*Power (version 3.1.9.6, Universität Düsseldorf, Germany), with calculations based on an ANOVA repeated measures within-between interaction. Assuming a medium effect size of 0.5, a power of 0.85, two groups, and three measurements, the recommended sample size was 10 participants.

To be included in the study, participants had to meet the following criteria: (i) actively training as archers at least twice a week for the past six months; (ii) no recent history of injury or illness; (iii) being over 18 years old; and (iv) committing to all phases of the study. Exclusion criteria were: (i) sustaining an injury or illness during the study.

Initially, 50 archers were considered for the study, but 30 were excluded due to upper limb injuries or refusal to participate. The final sample included twenty archers (14 men and 6 women). The men athletes had an average age of 32.1 ± 6.6 years, a height of 179.9 ± 7.5 cm, a body mass of 81.5 ± 13.2 kg, 5.9 ± 5.1 years of archery experience, and a training frequency of 1.6 ± 0.8 sessions per week, with an average of 102.1 ± 40.4 shots per session. The women participants averaged 25.3 ± 5.0 years of age, 165.8 ± 2.6 cm in height, 69.7 ± 23.6 kg in body mass, 4.5 ± 4.3 years of experience, and trained 1.7 ± 0.8 sessions per week, with an average of 131.7 ± 56.7 shots per session.

Manual therapy

A single intervention session was conducted with the participants. The intervention took place on the same day of the week, after archery training and a 30-minute rest period following the firing of 100 arrows to ensure repeatability. Participants received an active intervention that included passive manipulation. Prior to starting, participants were given verbal information about the intervention. The manipulation involved three-dimensional movements aimed at increasing muscle stimulation. A qualified physiotherapist with 25 years of manual therapy experience performed the manipulations, ensuring consistency by delivering the intervention personally each time.

The procedure began with the participant sitting and positioning their upper limb in internal rotation, extension, and adduction (hand and forearm placed on the back side). This initial positioning was intended to tighten and lengthen the infraspinatus and trapezius ascending muscles. The therapist then prepared for the shoulder joint pre-tension phase by gently increasing capsular tension from level II to level III, ensuring the participant's comfort and that no pain was felt.

Each manipulation proceeded to stage III until tissue tension was detected. A 2-second third-degree tension was then applied, followed by manipulations in the superior-lateral direction. This therapeutic protocol was administered once to each participant. The appropriate preparation of the shoulder girdle for the application of the manipulation technique was aimed at increasing the pretension of the infraspinatus muscle. By setting up the maneuver, the muscle fibers can be more stimulated.

Procedures

The muscle fatigue assessment was conducted on the string limb, predominantly the right limb for right-handed archers (19 right-handed, 1 left-handed). Each archery shot involves five distinct phases: pre-shot, set-up, drawing, aiming, and release. The pre-shot phase involves preparing the bow and loading the arrow. During the set-up phase, the archer positions themselves and starts the draw. The drawing phase involves pulling back the bowstring, engaging the muscles of the horizontal string arm. In the aiming phase, the bowstring is fully drawn, requiring isometric muscle contraction to maintain the position. The release phase involves the archer extending their fingers to release the string, followed by lowering their arms and relaxing the muscles.

After completing a standardized warm-up protocol led by a researcher—which included 10 minutes of dynamic stretching for the upper limbs and 5 minutes of isometric exercises for the upper limbs—participants underwent their baseline assessment. These assessments took place in the same shooting range, within a dedicated room equipped with the research instruments (EMG), maintained at a temperature of 23°C and a relative humidity of 55%. To avoid disturbing the athletes, assessments were performed individually. Two investigators conducted the assessments: one specialized in EMG instrumentation and the other in physical performance evaluation.

During the initial evaluation (prior to training), participants received an introduction to the tests and were acquainted with the equipment. They had the opportunity to practice each test without data collection to ensure familiarity. Participants underwent testing while executing the shooting phases (pre-shot, set-up, drawing, aiming, and release phases), with sEMG activity measured in selected muscles: middle deltoid, posterior deltoid, upper trapezius, middle trapezius, lower trapezius, and infraspinatus. Each muscle was assessed three times during the aiming phase.

Measurements

Surface EMG data were captured for the middle deltoid, posterior deltoid, upper trapezius, middle trapezius, lower trapezius, and infraspinatus during the maximum voluntary isometric contraction phase (3-second was recorded). The SEMG data was gathered and differentially amplified with a gain of 500 using TeleMyo DTS (Noraxon, Scottsdale, AZ, USA) along with Ag/AgCl 1-cm2 surface electrodes (Sorimex, Toruń, Poland). Band-pass filtering was applied to the SEMG signals (15–500 Hz), and they were sampled at 1500 Hz (16-bit resolution) using an analog-to-digital converter. Subsequently, the SEMG data was archived and processed further using MyoResearch 2.8 software (Noraxon). Electrode placement and skin preparation, including shaving, abrasion, and cleaning with alcohol, adhered to the SENIAM recommendations (Hermens et al., 2000). Signal processing involved full rectification and smoothing using the root mean square (EMG$_{RMS}$) method with a 300 ms moving time window. The following SEMG outcomes were analyzed: mean and maximal amplitude of EMG$_{RMS}$ (in µV) and the median frequency of the raw SEMG signal power spectrum (EMG$_{MED}$, in Hz).

Statistical procedures

Descriptive statistics, including means and standard deviations, were presented. Before proceeding with inferential statistics, the normality of the sample was assessed, and confirmation was sought through the Kolmogorov-Smirnov test ($p > 0.05$). Similarly, verification of the assumption of homogeneity was conducted using Levene's test ($p > 0.05$). Given the study's design (three assessments for two groups), a mixed ANOVA was utilized to analyze interactions between time and groups. This analysis also involved calculating partial eta squared (η_p^2). Furthermore, post-hoc comparisons were conducted using the Bonferroni test. All statistical analyses were performed using SPSS software (IBM SPSS Statistics, Version 29.0.2.0 Armonk, NY: IBM Corp), with a predetermined significance level of $p < 0.05$.

Results

Table 1 shows the descriptive statistics of the EMG measures for the middle, posterior deltoid and infraspinatus between sexes.

No significant interaction between time and group was found in the middle deltoid when considering the mean amplitude EMG $_{RMS}$ (F=0.324; p=0.650; η_p^2=0.018), maximal amplitude EMG $_{RMS}$ (F=0.406; p=0.582; η_p^2=0.022), and EMG $_{MED}$ (F=2.012; p=0.148; η_p^2=0.101). Significant differences over time were observed in the middle deltoid for the mean amplitude EMG $_{RMS}$ (F=5.913; p=0.014; η_p^2=0.247), and maximal amplitude EMG $_{RMS}$ (F=4.161; p=0.044; η_p^2=0.188), although no significant differences were found in EMG $_{MED}$ (F=0.004; p=0.996; η_p^2<0.001). Specifically, after 100 shots, the mean amplitude EMG $_{RMS}$ significantly increased compared to the baseline (196.1 vs. 248.9 µV; p=0.002).

No significant interaction between time and group was found in the posterior deltoid when considering the mean amplitude EMG $_{RMS}$ (F=0.013; p=0.987; η_p^2=0.001), maximal amplitude EMG $_{RMS}$ (F=0.949; p=0.345; η_p^2=0.050), and EMG $_{MED}$ (F=2.343; p=0.132; η_p^2=0.115). No significant differences over time were observed in the posterior deltoid for the mean amplitude EMG $_{RMS}$ (F=2.089; p=0.139; η_p^2=0.104), maximal amplitude EMG $_{RMS}$ (F=1.434; p=0.247; η_p^2=0.074), and in EMG $_{MED}$ (F=1.680; p=0.210; η_p^2=0.085).

No significant interaction between time and group was found in the infraspinatus when considering the mean amplitude EMG $_{RMS}$ (F=0.495; p=0.562; η_p^2=0.027), maximal amplitude EMG $_{RMS}$ (F=0.404; p=0.653; η_p^2=0.022), and EMG $_{MED}$ (F=2.530; p=0.123; η_p^2=0.123). Significant differences over time were observed in the infraspinatus for the mean amplitude EMG $_{RMS}$ (F=8.480; p=0.003; η_p^2=0.320), maximal amplitude EMG $_{RMS}$ (F=7.357; p=0.002; η_p^2=0.290), and EMG $_{MED}$ (F=5.460; p=0.025; η_p^2=0.233). Post-hoc comparisons revealed a significantly greater mean amplitude EMG $_{RMS}$ after manual therapy compared to after 100 shots (169.7 vs. 109.8 µV; p=0.008). Similar results were observed for maximal amplitude EMG $_{RMS}$ (372.7 vs. 209.5 µV; p=0.010).

Table 1.
Descriptive statistics (mean ± standard deviation) of the electromyography measures for the middle, posterior deltoid, and infraspinatus between sexes.

	Men (n=14)	Women (n=6)	Between-group analysis
Middle deltoid			
Mean ampl. EMG $_{RMS}$ (µV)			
Baseline	184.6±126.0^{b}	207.6±127.6^{b}	F=0.139; p=0.714; η_p^2=0.008
Post 100 shots	227.2±175.0^{a}	270.6±113.2^{a}	F=0.309; p=0.585; η_p^2=0.017
Post manual therapy	240.6±216.1	256.7±117.1	F=0.029; p=0.867; η_p^2=0.002
Max. ampl. EMG $_{RMS}$ (µV)			
Baseline	391.0±254.0	421.1±222.9	F=0.063; p=0.805; η_p^2=0.003
Post 100 shots	500.9±401.4	514.2±244.1	F=0.006; p=0.941; η_p^2=0.003
Post manual therapy	513.7±430.0	477.2±220.8	F=0.038; p=0.847; η_p^2=0.002
EMG$_{MED}$ (Hz)			
Baseline	69.3±17.3	75.3±12.5	F=0.576; p=0.458; η_p^2=0.031
Post 100 shots	74.6±19.4	69.5±25.1	F=0.243; p=0.628; η_p^2=0.013
Post manual therapy	71.4±15.1	73.0±8.7	F=0.057; p=0.813; η_p^2=0.003
Posterior deltoid			
Mean ampl. EMG $_{RMS}$ (µV)			
Baseline	328.1±180.9	369.5±189.1	F=0.215; p=0.649; η_p^2=0.012

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Post 100 shots	375.5±204.8	412.0±157.1	F=0.150; p=0.703; η_p^2=0.008
Post manual therapy	375.1±168.7	408.7±151.4	F=0.176; p=0.679; η_p^2=0.010
Max. ampl. EMG $_{\mathrm{RMS}}$ (μV)			
Baseline	634.4±338.6	656.7±321.9	F=0.019; p=0.893; η_p^2=0.001
Post 100 shots	749.1±379.8	830.5±383.1	F=0.192; p=0.667; η_p^2=0.011
Post manual therapy	1324.0±1383.5	789.8±320.3	F=0.849; p=0.369; η_p^2=0.045
EMG$_{\mathrm{MED}}$ (Hz)			
Baseline	63.3±11.6^{b}	60.1±6.8	F=0.395; p=0.538; η_p^2=0.021
Post 100 shots	67.5±12.0^{a,c}	61.2±5.8	F=1.497; p=0.237; η_p^2=0.077
Post manual therapy	59.2±11.2^{b}	61.9±6.2	F=0.313; p=0.582; η_p^2=0.017
Infraspinatus			
Mean ampl. EMG $_{\mathrm{RMS}}$ (μV)			
Baseline	151.5±72.8	154.2±86.6	F=0.005; p=0.942; η_p^2<0.001
Post 100 shots	121.7±39.2	97.9±32.5	F=1.698; p=0.209; η_p^2=0.086
Post manual therapy	169.1±88.2	170.4±82.0	F=0.001; p=0.975; η_p^2<0.001
Max. ampl. EMG $_{\mathrm{RMS}}$ (μV)			
Baseline	316.9±156.8	326.2±238.0	F=0.011; p=0.919; η_p^2=0.001
Post 100 shots	241.6±75.2^{c}	177.3±52.1	F=3.596; p=0.074; η_p^2=0.167
Post manual therapy	398.1±229.0^{b}	347.3±200.2	F=0.220; p=0.644; η_p^2=0.012
EMG$_{\mathrm{MED}}$ (Hz)			
Baseline	54.3±14.2	64.4±17.1	F=1.905; p=0.184; η_p^2=0.096
Post 100 shots	51.5±10.2	48.9±16.9	F=0.193; p=0.666; η_p^2=0.011
Post manual therapy	55.4±11.2	68.3±20.4	F=3.425; p=0.081; η_p^2=0.160

EMG: electromyography; EMG$_{\mathrm{ME}}$: median frequency of raw SEMG signal power spectrum; RMS: root mean square; a: significantly different from baseline ($p<0.05$); b: significantly different from after 50 shots ($p<0.05$); c: significantly different from after 100 shots ($p<0.05$)

Table 2 shows the descriptive statistics of the EMG measures for the upper, middle and low trapezius between sexes.

No significant interaction between time and group was found in the upper trapezius when considering the mean amplitude EMG $_{\mathrm{RMS}}$ (F=0.271; p=0.621; η_p^2=0.015), maximal amplitude EMG $_{\mathrm{RMS}}$ (F=0.351; p=0.599; η_p^2=0.019), although significant interactions were found in EMG $_{\mathrm{MED}}$ (F=4.147; p=0.024; η_p^2=0.187). No significant differences over time were observed in the upper trapezius for the mean amplitude EMG $_{\mathrm{RMS}}$ (F=3.624; p=0.070; η_p^2=0.168), although significant differences were found in maximal amplitude EMG $_{\mathrm{RMS}}$ (F=6.695; p=0.013; η_p^2=0.271), and in EMG $_{\mathrm{MED}}$ (F=3.398; p=0.052; η_p^2=0.159). Post-hoc comparisons revealed a significantly smaller maximal amplitude EMG $_{\mathrm{RMS}}$ in baseline compared to after 100 shots (312.6 vs. 463.9 μV; p=0.014) and after manual therapy (312.6 vs. 551.2 μV; p=0.045).

Significant interaction between time and group was found in the middle trapezius when considering the maximal amplitude EMG $_{\mathrm{RMS}}$ (F=4.364; p=0.043; η_p^2=0.195), although no significant differences were found in mean amplitude EMG $_{\mathrm{RMS}}$ (F=1.879; p=0.184; η_p^2=0.095), and EMG $_{\mathrm{MED}}$ (F=0.410; p=0.667; η_p^2=0.022). Significant differences over time were observed in the middle trapezius for the maximal amplitude EMG $_{\mathrm{RMS}}$ (F=5.294; p=0.026; η_p^2=0.227), although no significant differences were found in mean amplitude EMG $_{\mathrm{RMS}}$ (F=1.094; p=0.323; η_p^2=0.057), and EMG $_{\mathrm{MED}}$ (F=0.479; p=0.501; η_p^2=0.026). Post-hoc comparisons revealed a significantly smaller maximal amplitude EMG $_{\mathrm{RMS}}$ in baseline compared to after 100 shots (362.8 vs. 723.4 μV; p=0.048).

No significant interaction between time and group was found in the low trapezius when considering the mean amplitude EMG $_{\mathrm{RMS}}$ (F=0.271; p=0.621; η_p^2=0.015), maximal amplitude EMG $_{\mathrm{RMS}}$ (F=0.351; p=0.599; η_p^2=0.019), although significant interactions were found in EMG $_{\mathrm{MED}}$ (F=4.147; p=0.024; η_p^2=0.187). No significant differences over time were observed in the low trapezius for the mean amplitude EMG $_{\mathrm{RMS}}$ (F=3.624; p=0.070; η_p^2=0.168), although significant differences were found in maximal amplitude EMG $_{\mathrm{RMS}}$ (F=6.695; p=0.013; η_p^2=0.271), and in EMG $_{\mathrm{MED}}$ (F=0.398; p=0.044; η_p^2=0.159). Post-hoc comparisons revealed a significantly smaller maximal amplitude EMG $_{\mathrm{RMS}}$ in baseline compared to after 100 shots (312.6 vs. 463.9 μV; p=0.014) and after manual therapy (312.6 vs. 551.2 μV; p=0.045).

Table 2.
Descriptive statistics (mean ± standard deviation) of the electromyography measures for the upper trapezius, middle trapezius, lower trapezius between sexes.

	Men (n=14)	Women (n=6)	Between-group analysis
Upper trapezius			
Mean ampl. EMG $_{\mathrm{RMS}}$ (μV)			
Baseline	143.7±74.5^{b}	113.1±97.2	F=0.593; p=0.451; η_p^2=0.032
Post 100 shots	197.2±104.7^{a}	149.7±137.0	F=0.721; p=0.407; η_p^2=0.039
Post manual therapy	282.9±263.8	193.6±158.8	F=0.584; p=0.455; η_p^2=0.031
Max. ampl. EMG $_{\mathrm{RMS}}$ (μV)			
Baseline	363.8±201.0^{b,c}	261.4±244.5	F=0.962; p=0.340; η_p^2=0.051
Post 100 shots	568.7±295.6^{a}	359.0±303.9	F=2.082; p=0.166; η_p^2=0.104
Post manual therapy	640.9±483.4^{a}	461.5±360.0	F=0.660; p=0.427; η_p^2=0.035

EMG_{MED} (Hz)			
Baseline	73.3±14.3	62.2±18.9^{c}	F=2.101; p=0.164; η_p^2=0.105
Post 100 shots	67.0±11.7	70.8±20.3	F=0.285; p=0.600; η_p^2=0.016
Post manual therapy	71.5±8.4	83.2±14.7^{a}	F=5.096; p=0.037; η_p^2=0.221*
Middle trapezius			
Mean ampl. EMG_{RMS} (μV)			
Baseline	212.3±114.9	147.8±85.2	F=1.516; p=0.234; η_p^2=0.078
Post 100 shots	199.2±102.9	219.7±115.9	F=0.154; p=0.699; η_p^2=0.008
Post manual therapy	207.5±113.2	214.6±107.0	F=0.017; p=0.897; η_p^2=0.001
Max. ampl. EMG_{RMS} (μV)			
Baseline	405.8±262.2	319.7±174.3^{b}	F=0.536; p=0.474; η_p^2=0.029
Post 100 shots	464.4±280.6	982.4±974.1^{a}	F=3.516; p=0.077; η_p^2=0.163
Post manual therapy	488.6±271.0	446.0±218.6	F=0.115; p=0.739; η_p^2=0.006
EMG_{MED} (Hz)			
Baseline	80.3±77.1	67.2±9.5	F=0.167; p=0.687; η_p^2=0.009
Post 100 shots	60.9±10.1	61.0±23.6^{c}	F<0.001; p=0.983; η_p^2<0.001
Post manual therapy	61.2±10.1	71.7±13.6^{b}	F=3.731; p=0.069; η_p^2=0.172
Lower trapezius			
Mean ampl. EMG_{RMS} (μV)			
Baseline	172.3±85.9	212.7±141.1	F=0.634; p=0.436; η_p^2=0.034
Post 100 shots	122.5±52.5	181.7±73.4	F=4.221; p=0.055; η_p^2=0.190
Post manual therapy	170.6±98.6	251.8±210.9	F=1.429; p=0.247; η_p^2=0.074
Max. ampl. EMG_{RMS} (μV)			
Baseline	384.0±192.2^{b}	396.1±183.6	F=0.017; p=0.897; η_p^2=0.001
Post 100 shots	237.3±75.2^{a,c}	317.1±102.9	F=3.807; p=0.067; η_p^2=0.175
Post manual therapy	432.0±258.5^{b}	537.8±453.0	F=0.446; p=0.513; η_p^2=0.024
EMG_{MED} (Hz)			
Baseline	51.0±6.3	56.5±8.1	F=2.759; p=0.114; η_p^2=0.133
Post 100 shots	51.4±8.8	56.7±9.2	F=1.454; p=0.244; η_p^2=0.075
Post manual therapy	53.2±8.7	60.2±9.9	F=2.504; p=0.131; η_p^2=0.122

EMG: electromyography; EMG_{ME}: median frequency of raw SEMG signal power spectrum; RMS: root mean square; a: significantly different from baseline ($p<0.05$); b: significantly different from after 50 shots ($p<0.05$); c: significantly different from after 100 shots ($p<0.05$)

Figure 1 shows the mean EMG RMS amplitude standardized to the maximum voluntary contraction

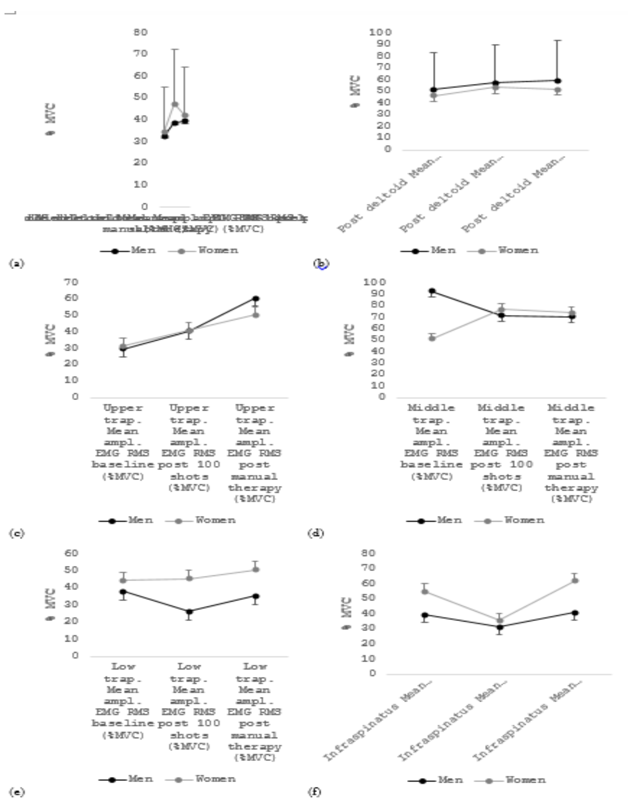

Figure 1. Normalized values of mean amplitude EMG RMS considering the maximum voluntary contraction (MVC). (a) Middle deltoid; (b) Posterior deltoid; (c) Upper trapezius; (d) Middle trapezius; (e) Lower trapezius; and (f) Lower trapezius.

Discussion

The results of our study, though not controlled, revealed that manual therapy focused on shoulder mobilization, applied after a fatigue condition induced by 100 archery shots, generally did not significantly impact the changes promoted by this condition in athletes. In the case of the infraspinatus muscle, post-hoc comparisons showed a significantly greater mean amplitude EMG_{RMS} after manual therapy compared to after 100 shots, indicating a continuous decline of EMG parameters even after manual therapy. Specific exceptions were observed in the upper and middle trapezius muscles, where women significantly benefited from an increase in EMG_{MED} after manual therapy. However, the remaining results did not show a particularly interesting impact of manual therapy in improving EMG parameters. In men, the EMG_{MED} in the posterior deltoid significantly decreased after manual therapy compared to after 100 shots. Additionally, in the infraspinatus, as well as the lower and upper trapezius muscles, the maximal amplitude EMG_{RMS} continued to significantly increase after manual therapy compared to after 100 shots, suggesting continuous impairment of these EMG parameters. Our study also revealed that sex had no significant impact on the effects promoted by fatigue or manual therapy in archery athletes, with the only observed significant interaction between time and sex group being in the infraspinatus muscle. The infraspinatus muscle may respond differently to fatigue or manual therapy due to subtle variations in muscle composition or neural activation patterns between sexes. However,

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the overall effects of fatigue and manual therapy appear consistent across sexes, indicating that sex-related differences in this context are minimal and specific to certain muscles.

After manual therapy aimed at enhancing shoulder mobility, the archers did not exhibit improvements in the impairment of EMG parameters, such as mean and maximal EMG_{RMS}, and the EMG_{MED}, following fatigue. Manual therapy primarily focuses on enhancing joint range of motion and reducing muscular tightness, which can improve range of motion and potentially alleviate pain (Bishop et al., 2015). However, the neuromuscular adaptations responsible for fatigue resistance and motor unit recruitment patterns during repetitive high-intensity activities, such as archery, are more deeply rooted in the central and peripheral nervous systems (Carpentier et al., 2001). Fatigue results in altered motor unit recruitment, reduced firing rates, and increased synchronization (Boonstra et al., 2008), which are not significantly influenced by manual therapy that primarily targets soft tissue and joint mechanics.

Moreover, the mechanical reasons for the lack of improvement in EMG parameters post-manual therapy can be attributed to the nature of muscular fatigue and the specific demands of archery (Merletti & Parker, 2004). While manual therapy may help in temporarily alleviating muscle stiffness and improving blood flow (Best et al., 2008), it does not may directly address the metabolic and energetic impairments caused by repetitive high-intensity activity. Additionally, the specific shoulder movements required in archery involve fine motor control and stabilization, which are highly dependent on efficient neuromuscular coordination and endurance, rather than just range of motion (Beyaz et al., 2024). Therefore, while manual therapy can enhance mobility, it does not may significantly influence the intrinsic muscle endurance and neuromuscular efficiency required to maintain optimal EMG parameters under conditions of fatigue.

After manual therapy, the archers exhibited a significant decline in the case of the infraspinatus muscle, as evidenced by post-hoc comparisons showing a significantly greater mean amplitude EMG_{RMS} after manual therapy compared to after 100 shots, indicating a continuous decline of EMG parameters even after manual therapy. In this specific case, manual therapy may potentially exacerbated muscle fatigue by altering the muscle's biomechanical properties or disrupting its neuromuscular control mechanisms (Clark et al., 2012). Additionally, the repetitive nature of archery imposes substantial mechanical stress on the shoulder musculature, leading to muscle fatigue and possibly micro-trauma, which can further impair muscle function even after therapeutic intervention (Simsek et al., 2018). Therefore, the observed decline in EMG parameters post-manual therapy could stem from a combination of disrupted neuromuscular control, altered muscle biomechanics, and persistent mechanical stressors inherent in archery.

Our findings also showed that, except for infraspinatus where a time and sex group interaction was observed, there was generally no significant impact of sex on most of the results. The lack of substantial differences in the response to manual therapy between men and women athletes for most muscles may be attributed the similarity in the fundamental neural control of muscle function between sexes. Both men and women share comparable motor unit recruitment patterns and firing rates when performing similar tasks, particularly in muscles that are not heavily influenced by hormonal or structural differences (Tiller et al., 2021). This commonality in motor control likely leads to similar responses to interventions like manual therapy.

Additionally, the physiological mechanisms of muscle fatigue and recovery tend to be broadly similar across sexes, especially in muscles that are not as sexually dimorphic (O'Bryan et al., 2022). For instance, the process of muscle fatigue involves the depletion of energy stores, accumulation of metabolic byproducts like lactate, and the disruption of excitation-contraction coupling, which are processes that do not differ markedly between men and women (Lambert et al., 2005). Consequently, the response of these fatigued muscles to interventions such as manual therapy would also be expected to be similar, leading to the observed lack of substantial differences.

Moreover, while there are sex differences in muscle fiber composition, with men typically having a higher percentage of type II (fast-twitch) fibers and women having a slightly greater proportion of type I (slow-twitch) fibers (Tiller et al., 2021), these differences might not be enough to create substantial differences in response to manual therapy in most muscles.

Nevertheless, it was interesting to note that following the completion of 100 shots, manual therapy demonstrated significant positive effects on women. Specifically, there was a significant enhancement in the activation of the upper and middle trapezius muscles, with women experiencing a significant increase in EMG_{MED} following manual therapy. The observed increase in EMG activity in the upper and middle trapezius muscles in women after manual therapy could be attributed to sex-specific neuromuscular adaptations or differences in muscle fiber composition, leading to enhanced muscle recruitment and efficiency (Tiller et al., 2021). Additionally, manual therapy might reduce muscle tension or improve proprioception more effectively in women, thereby optimizing motor unit activation during archery tasks. However, further research exploring the interplay between hormonal factors, muscle fiber composition, and biomechanics in the context of manual therapy interventions during specific tasks is warranted to elucidate the underlying mechanisms driving sex-specific differences in neuromuscular adaptations.

Although our results, the study presents some limitations and avenues for future research. Firstly, although the results shed light on the effects of manual therapy on shoulder mobilization following archery-induced fatigue, the lack of a control group limits the ability to establish causality. Future studies should incorporate control groups to better elucidate the specific effects of manual therapy on neuromuscular parameters. Moreover, the challenge of recruiting athletes led to a heterogeneous sample of men and women, which may have influenced the results. Future studies should aim to increase the overall sample size and ensure a more balanced representation of men and women. Additionally, the observed decline in EMG parameters, particularly in the infraspinatus muscle, after manual therapy suggests potential exacerbation of muscle fatigue or disruption of neuromuscular control mechanisms. Further investigations are necessary to understand the underlying mechanisms behind these effects and to improve manual therapy techniques to mitigate such outcomes. Moreover, while sex differences were not prominently displayed in most results, the significant improvement observed in women's upper and middle trapezius muscle activation following manual therapy highlights the need for more research into sex-specific neuromuscular adaptations and the role of hormonal factors in manual therapy interventions. A final limitation is that we did not compare different durations of exposure to manual therapy, which could affect the outcomes given the individualization process. Future studies should investigate the effects of varying time periods of manual therapy to better understand its impact.

The findings of this study highlight that manual therapy has limited effectiveness in restoring EMG parameters following fatigue in archers, suggesting the need to explore additional regenerative strategies that can specifically target these parameters. Moreover, adjusting training plans to prevent extreme fatigue conditions is warranted, while acknowledging that the recovery process is multifaceted and influenced by various factors. Despite manual therapy not being particularly effective in improving EMG parameters, its effectiveness in addressing other variables such as pain and range of motion should not be overlooked, as these are also crucial aspects of the recovery process. Therefore, a broader range of regenerative interventions should be considered, with a focus on individualized approaches tailored to athletes' responses.

Conclusions

The main results of the current study suggest that, in general, manual therapy focused on shoulder mobilization in archers exposed to fatigue from repeated shots did not significantly improve the EMG parameters that were impaired due to fatigue. In fact, in some cases, such as the infraspinatus, a significantly greater mean amplitude EMG_{RMS} was observed after manual therapy compared to after 100 shots. Generally, no significant differences were found across the various muscles regarding sex-related effects, with the exception of a favorable outcome observed in women. Specifically, a significant improvement in the EMG_{MED} of the upper and middle trapezius was noted after manual therapy compared to after 100 shots. Thus, it seems that other regenerative techniques, and potentially better management of fatigue conditions in archery training, must be implemented to avoid the decline in muscle activity of the primary muscles that support the archery movement. This aims to mitigate the decline in performance and, most importantly, the potentially increased injury risk caused by impaired muscle activity.

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