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MUSCULAR COORDINATION OF MOVEMENTS ASSOCIATED WITH ARROW RELEASE IN ARCHERY

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ABSTRACT

The aim of this study was to examine the muscular activation strategy of archers with different levels of expertise. Twenty-seven (27) male archers volunteered to participate in the current study. The activation of nine forearm and shoulder girdle muscles were analysed. Statistically significant differences were observed among the archery groups in the activation of muscles (flexor digitorum superficialis, extensor digitorum communis, deltoids middle, deltoids posterior, trapezius pars ascendens, trapezius pars transversa, and trapezius pars descendens) (p<0.05). The results of this study, indicated that in order to pull the bowstring, the elite archers used distal (forearm) muscles less, but used proximal (shoulder) and axial (trapezius) muscles more, while the mid-level and novice archers used distal muscles more. This differential muscle use was interpreted as the most important factor affecting the horizontal oscillation of the bowstring. To minimise horizontal oscillation, it is suggested that archers carry the weight with their axial and proximal muscles. The findings of the present study could be used as a reference to pave the way for the development of effective archery training, which would include visual or audial feedback methods.

Keywords: Archery; Electromyography (EMG); Muscular activation; Shooting.

INTRODUCTION

Archery can be described as an elegant and impulsive closed motor skill. It is a static sport that requires upper body strength and endurance, particularly of the forearm and shoulder girdle (Mann & Littke, 1989). Skill in archery is defined as the ability to shoot an arrow with accuracy at a given target within a certain time span and distance (Leroyer *et al*., 1993). The discipline involves a three-phase movement sequence (stance, drawing and aiming). Nishizono *et al*. (1987) divided the movement further into six phases: bow hold, drawing, full draw, aiming, release and follow-through. An archer pushes the bow with an extended arm held statically in the direction of the target, while the other arm dynamically pulls the bowstring from the beginning of the drawing phase until the release is executed (Leroyer *et al*., 1993). The release phase must be well balanced and highly reproducible for the archer to achieve commendable results in a competition (Nishizono *et al*., 1987). The bowstring is released when an audible impulse is received from the “clicker” that is a device used to check the draw length (Leroyer *et al*., 1993).

The speed of the reaction to the fall (sound) of the clicker is directly related to the archer's performance (Ertan *et al*., 1996). Thus, reaction time (RT), which is the interval between the stimulus and the response initiation, is used to classify archers as elite, intermediate or novice (Oxendine, 1968; Kerr, 1982; Schmidt, 1991; Latash, 1998). The electromyography (EMG) is silent for a substantial part of the RT, indicating that the command to move the finger has not yet reached the finger muscles (Schmidt, 1991). This latent period is the time required for the impulse to be transmitted from the sensory organs to the central nervous system and then to the muscles (Latash, 1998). Therefore, the muscle is activated late in the RT, and no movement occurs for 40 to 80 milliseconds.

Elite archers (Olympic and world championship medallists) display better RT values than intermediate and novice archers do (Landers *et al*., 1986). For this reason, the development of a repeated contraction and relaxation strategy in the forearm and pull-finger muscles is particularly important. The contraction and relaxation strategy used in the forearm muscle during bowstring release is critical for accurate and reproducible scoring in archery. Two different approaches to this strategy were proposed in previous studies, but they were not well defined (Nishizono *et al*., 1987; Clarys *et al*., 1990; Hennessy & Parker, 1990; Martin *et al*., 1990; McKinney & McKinney, 1997; Ertan *et al*., 2005; Ertan *et al*., 2011).

The first approach suggested that archers should release the bowstring through a sudden relaxation of the muscles that maintain the flexed position of the fingers around the bowstring rather than by attempting to affect the release moment by willingly extending the fingers through concentric antagonistic muscle action (Martin *et al*., 1990). In other words, this method suggests that the archer should relax the flexors, as the force of the string on the fingers is sufficient to produce extension. The active extension of the pull fingers is believed to cause lateral deflections of the bowstring and thus reduce consistency in terms of shot-to-shot performance (McKinney & McKinney, 1997, Ertan *et al.*, 2011).

The second approach suggested that the archer relax the flexors and contract the extensors. The muscular coordination of the agonist and antagonist muscles of the forearm is essential in this strategy, however, such coordination requires a relatively long training period (Nishizono *et al*., 1987; Clarys *et al*., 1990; Hennessy & Parker, 1990). Previous studies were not able to clarify the forearm muscle contraction and relaxation strategy that archers used (Nishizono *et al*., 1987; Clarys *et al*., 1990; Hennessy & Parker, 1990; Martin *et al*., 1990; McKinney & McKinney, 1997). All of the studies were confined to a limited number of elite archers.

Previously conducted studies have examined the shooting performances of only novice and elite archers, there is a lack of literature comparing the muscle activation strategies used by elite, mid-level and novice archers. In other words, the effect of performance level on this strategy was not investigated. The ability of archers to experience, learn and refine motor skills may affect their ability to perform the shooting process. After shooting training and practice, an archer's ability to perform shooting is usually improved. Prior experience with the task (or with a similar task) will also affect shooting performance. Moreover, the studies only involved the forearm muscles, which are crucial for accurate and reproducible scoring, while the effects of the activation patterns of the upper extremity muscles on archery shooting performance were not measured.

PURPOSE OF RESEARCH AND HYPOTHESES

The purpose of the present study was to investigate the various muscular activation strategies of the forearm, glenohumoral and scapular muscles [Muscle Flexor Digitorum Superficialis (MFDS), Muscle Extensor Digitorum Communis (MEDC), Muscle Deltoids Anterior (MDA), Muscle Deltoids Middle (MDM), Muscle Deltoids Posterior (MDP), Muscle Trapezius Pars Ascendens (MTPA), Muscle Trapezius Pars Transversa (MTPT), Muscle Trapezius Pars Descendens (MTPD) and Muscle Pectoralis Major Pars Clavicularis (MPMPC)] during shooting of archers with different levels of expertise. It was hypothesised that archers develop a specific forearm, pull finger, shoulder girdle and scapular joint muscle activation strategy by actively contracting the forearm extensors with the fall of the clicker.

METHODOLOGY

The University of Osman Gazi Human Research Ethics Board approved this study [2008/508], and subjects provided their informed written consent prior to participation.

Experimental design

This investigation used an experimental design to determine the various muscular activation strategies of the forearm, glenohumoral and scapular muscles during shooting of archers with different levels of expertise. The neuromuscular activation [EMG root mean square (RMS)] levels of the nine muscles (forearm, glenohumoral and scapular muscles) served as the dependent variables. The study consisted of one intervention. The measurements were performed at the Movement and Motor Control Laboratory at Anadolu University.

All of the archers completed a single test session. Before starting the test session, (a) the participants performed a 15-minute standardised warm-up consisting of five minutes of active upper body movement, five minutes of upper body stretching and five minutes of arrow shooting at short-distance targets, (b) the isometric maximum voluntary contraction (MVIC) of nine forearm and shoulder girdle muscles was recorded, and (c) archers were then tested at a short shooting distance (18 m, which is an official distance for indoor competitions in the archery field). A shooting cue was given by either of the researchers. The target face used was the official FITA 40-cm target for the 18-metre distance.

Participants were asked to use their own bow and arrows to ensure that each participant’s own shooting style and performance were maintained. Whenever the participants were in the stance phase, they were given a “start” command and EMG activities of the nine muscles were recorded.

Population and sample

Twenty-seven (27) male archers were divided into three groups according to their FITA scores [group I: elite archers (EA) >1150, n=9; group II: mid-level archers (MLA)=1100-1150, n=9; group III: novice archers (NA): <1100, n=9] volunteered to participate in the current study. Archers were considered skilled (elite) based on qualification scores of 1150 out of a maximum FITA score of 1440 in either nationally or internationally ranked competitions. All archers were right-handed, and recurve bows were used in this study. Their characteristics are summarised in Table 1. All of the participants were injury free at the time of testing, and none reported a previous upper or lower limb injury.

Table 1. MEANS AND STANDARD DEVIATIONS

Skill level	**Years of training** M±SD	**Age** M±SD	**Height (cm)** M±SD	**Body weight (kg)** M±SD	**FITA Scores** M±SD	**Drawing weight (kg)** M±SD
EA (n=9)	8.7±4.9[a,b]	25.5±8.3	178.6±6.0	78.5±11.5	1244.5±40.7[a,b]	44.0±1.4[a,b]
MLA (n=9)	6.6±3.3[c]	23.8±7.6	176.1±9.1	71.6±19.0	1150.3±12.0	35.5±3.9
NA (n=9)	1.4±0.5	22.6±6.0	176.5±4.9	72.1±17.2	915.2±15.9	34.8±2.8
p-value	$p<0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p<0.05$	$p<0.05$

EA=Elite Archer; MLA=Mid-Level Archer; NA=Novice Archer
M=Mean SD=Standard deviation Significance=$p<0.05$
[a] Difference between EA & NA [b] Difference between EA & MLA
[c] Differences between NA & MLA

Data collection

EMG data acquisition and analyses

The EMG activities of the nine muscles were recorded using surface electrodes [16-channel wireless surface electrodes (Delsys Trigno, USA)]. The pass band of the EMG amplifier, sampling rate, maximum intra-electrode impedance and CMMR were 20-50 0Hz, 2000 Hz, 6 kΩ and 95 dB, respectively. The subjects were prepared for EMG electrode placement by shaving the skin at each electrode site, cleaning it carefully with an alcohol swab and lightly abrading it to allow skin-electrode impedance (below 10 kΩ). The centre-to-centre distance between the two electrodes was 1cm in accordance with the recommendations for the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) (Hermens *et al*., 2000).

Prior to the shooting test, the isometric maximum voluntary contraction (MVIC) was recorded to normalise the EMG data of the muscles during arrow shooting. The MVIC of Muscle Flexor Digitorum Superficialis (MFDS), Muscle Extensor Digitorum Communis (MEDC), Muscle Deltoids Anterior (MDA), Muscle Deltoids Middle (MDM), Muscle Deltoids Posterior (MDP), Muscle Trapezius Pars Ascendens (MTPA), Muscle Trapezius Pars Transversa (MTPT), Muscle Trapezius Pars Descendens (MTPD) and Muscle Pectoralis Major Pars Clavicularis (MPMPC) were measured against static resistance, as described by Rota *et al.* (2013).

The snap of the clicker triggered 5-V transistor-transistor logic (TTL) signal, which was registered simultaneously with the myoelectric signals. Muscular activation 400ms before and 800 ms after the rise of the TTL signal were identified as the pre-clicker and post-clicker intervals. Each 20 Hz to 500 Hz band-pass-filtered and rectified EMG signal was divided into 100 ms epochs, and the root mean square (RMS) value of each epoch was calculated as the integrated EMG (iEMG).

Data analysis

The iEMGs from an average of six shots were used in the analysis. Descriptive statistics were computed to identify the characteristics of the subjects and groups. Mean scores were calculated for the six shots of each subject. The Kolmogorov-Smirnov (K-S) test was used to analyse whether the data fit a normal distribution. One-way analysis of variance (ANOVA) was conducted to compare nine muscles activities among the groups at each time interval. ANOVA was followed by Tukey's Post Hoc comparisons to determine the intervals during which significant differences occurred. A probability of $p<0.05$ was selected to indicate statistical significance.

RESULTS

In this study of elite, mid-level and novice archers, the muscular activation values of MFDS, MEDC, MDM, MDA, MDP, MPMPC, MTPD, MTPT and MTPA were compared. In Figure 1 A-F, the muscular activation 400ms before and 800ms after string release of the novice, mid-level and elite archers are shown. The RT of the archery groups are displayed in Figure 1 A-F (EA: 111.64±9.20ms; MLA: 140±11.98ms; NA: 167.22±16.98ms).

MFDS muscle (Figure 1A)

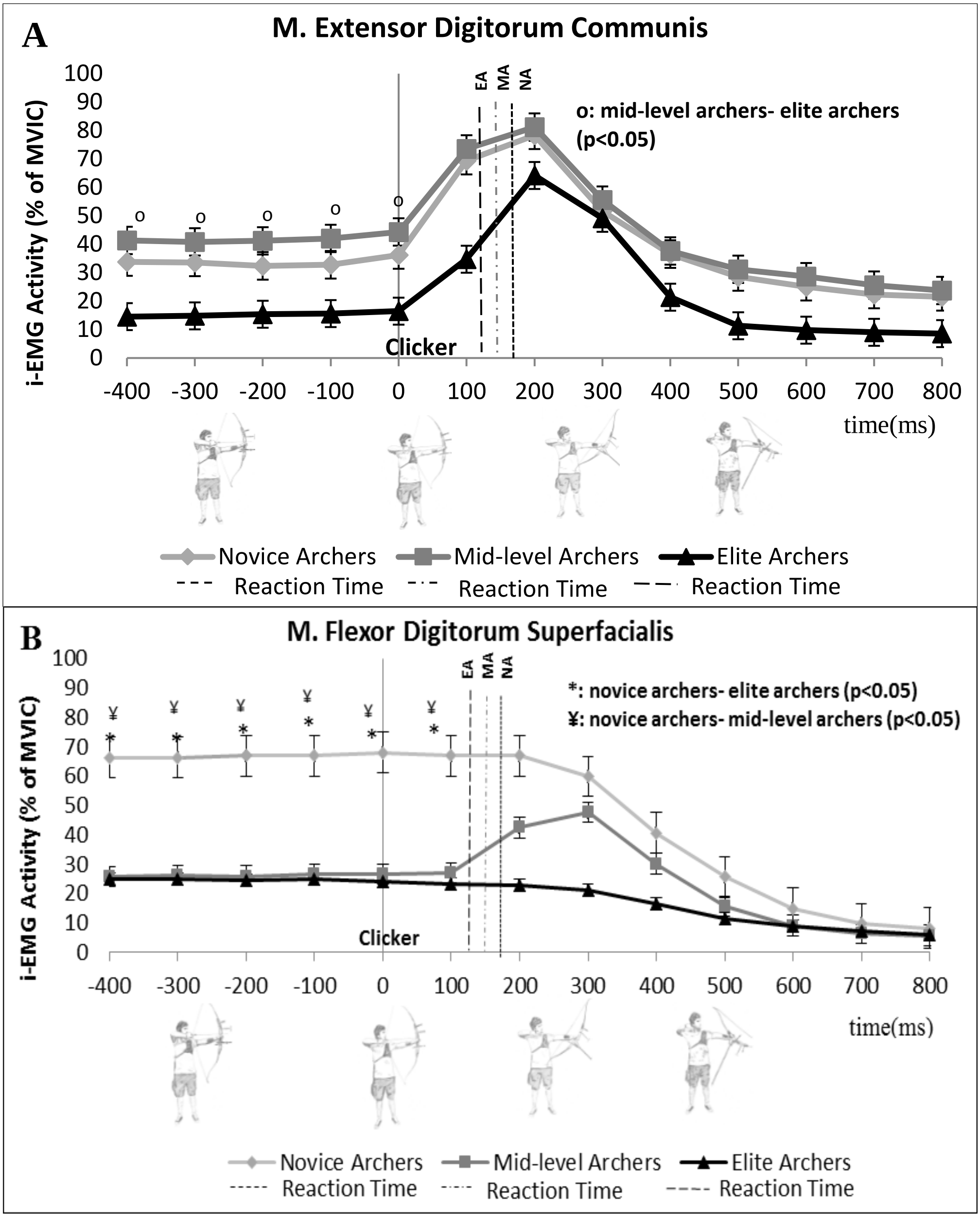
The MFDS EMG activities differed significantly ($p<0.05$) among the elite, mid-level and novice archers. The novice archers were observed to activate their forearm flexor muscles (66% of MVIC) more than the mid-level (26% of MVIC) and elite archers (25% of MVIC) did 400ms before the snap of the clicker during the aiming phase. As they released the bowstring, the flexor muscle activities of the novice and elite archers began to decrease gradually, while the mid-level archers' flexor muscle activities increased rapidly.

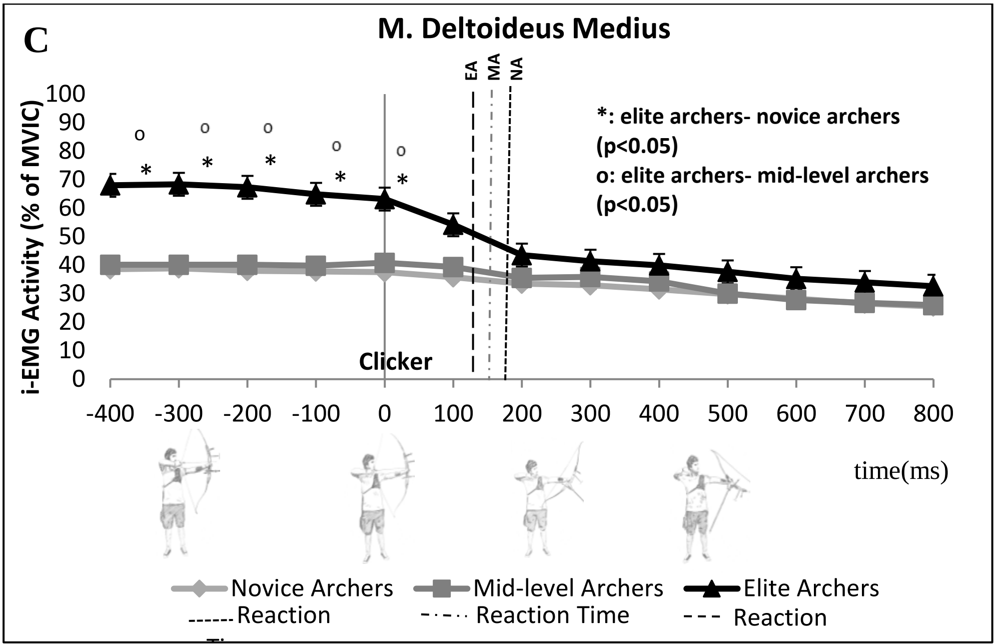
MEDC muscle (Figure 1B)

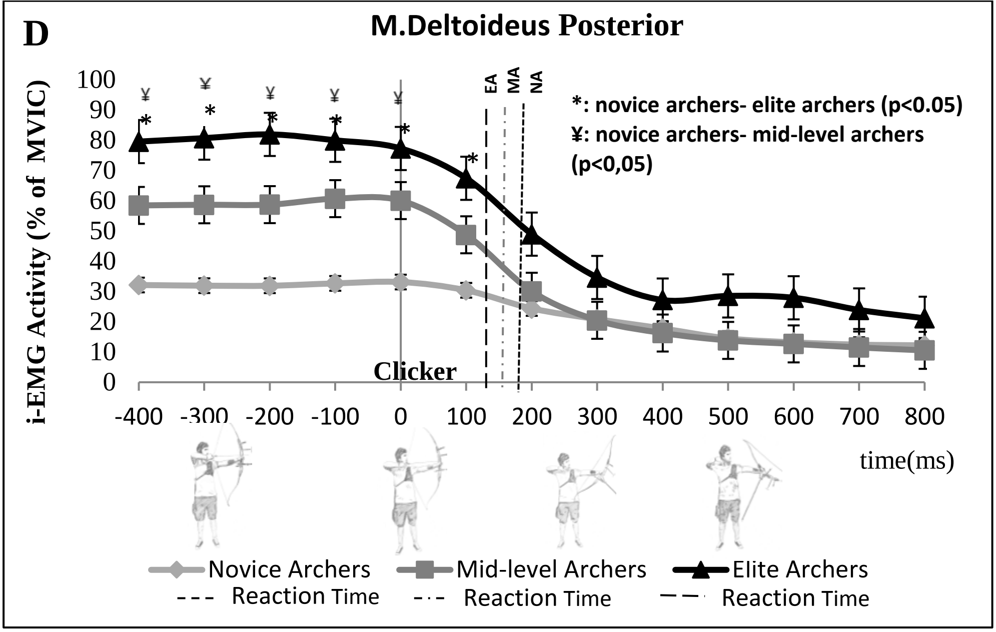
The MEDC EMG activities differed significantly ($p<0.05$) between the elite and mid-level archers. The mid-level archers were observed to activate their forearm extensor muscles (41% of MVIC) more than the novice archers (34% of MVIC) and elite archers (15% of MVIC) did 400ms before the snap of the clicker during the aiming phase. As the archers released the bowstring, the extensor muscle activity began to increase. Compared with the novice and mid-level archers, the elite archers showed lower MVIC percentages for the extensor muscle activities during all phases of shooting.

MDM muscle (Figure 1C)

The MDM EMG activities differed significantly ($p<0.05$) among the elite, mid-level and novice archers. The MDM EMG activation of the mid-level (40% of MVIC) and novice archers (40% of MVIC) was lower than that of the elite archers (68% of MVIC) from 400ms to 100ms when the clicker snapped and the elite archers demonstrated sudden MDM relaxation (54% of MVIC), which was not observed in the other groups.


A
M. Extensor Digitorum Communis
i-EMG Activity (% of MVIC)
0
10
20
30
40
50
60
70
80
90
100
EA
MA
NA
o: mid-level archers- elite archers (p<0.05)
o
Clicker
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
time(ms)
Novice Archers
Mid-level Archers
Elite Archers
Reaction Time
Reaction Time
Reaction Time
B
M. Flexor Digitorum Superfacialis
i-EMG Activity (% of MVIC)
0
10
20
30
40
50
60
70
80
90
100
EA
MA
NA
*: novice archers- elite archers (p<0.05)
¥: novice archers- mid-level archers (p<0.05)
¥
*
Clicker
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
time(ms)
Novice Archers
Mid-level Archers
Elite Archers
Reaction Time
Reaction Time
Reaction Time


C
M. Deltoideus Medius
EA
MA
NA
*: elite archers- novice archers (p<0.05)
o: elite archers- mid-level archers (p<0.05)
i-EMG Activity (% of MVIC)
100
90
80
70
60
50
40
30
20
10
0
Clicker
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
time(ms)
Novice Archers
Mid-level Archers
Elite Archers
Reaction
Reaction Time
Reaction


D
M.Deltoideus Posterior
EA
MA
NA
*: novice archers- elite archers (p<0.05)
¥: novice archers- mid-level archers (p<0,05)
i-EMG Activity (% of MVIC)
100
90
80
70
60
50
40
30
20
10
0
Clicker
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
time(ms)
Novice Archers
Mid-level Archers
Elite Archers
Reaction Time
Reaction Time
Reaction Time

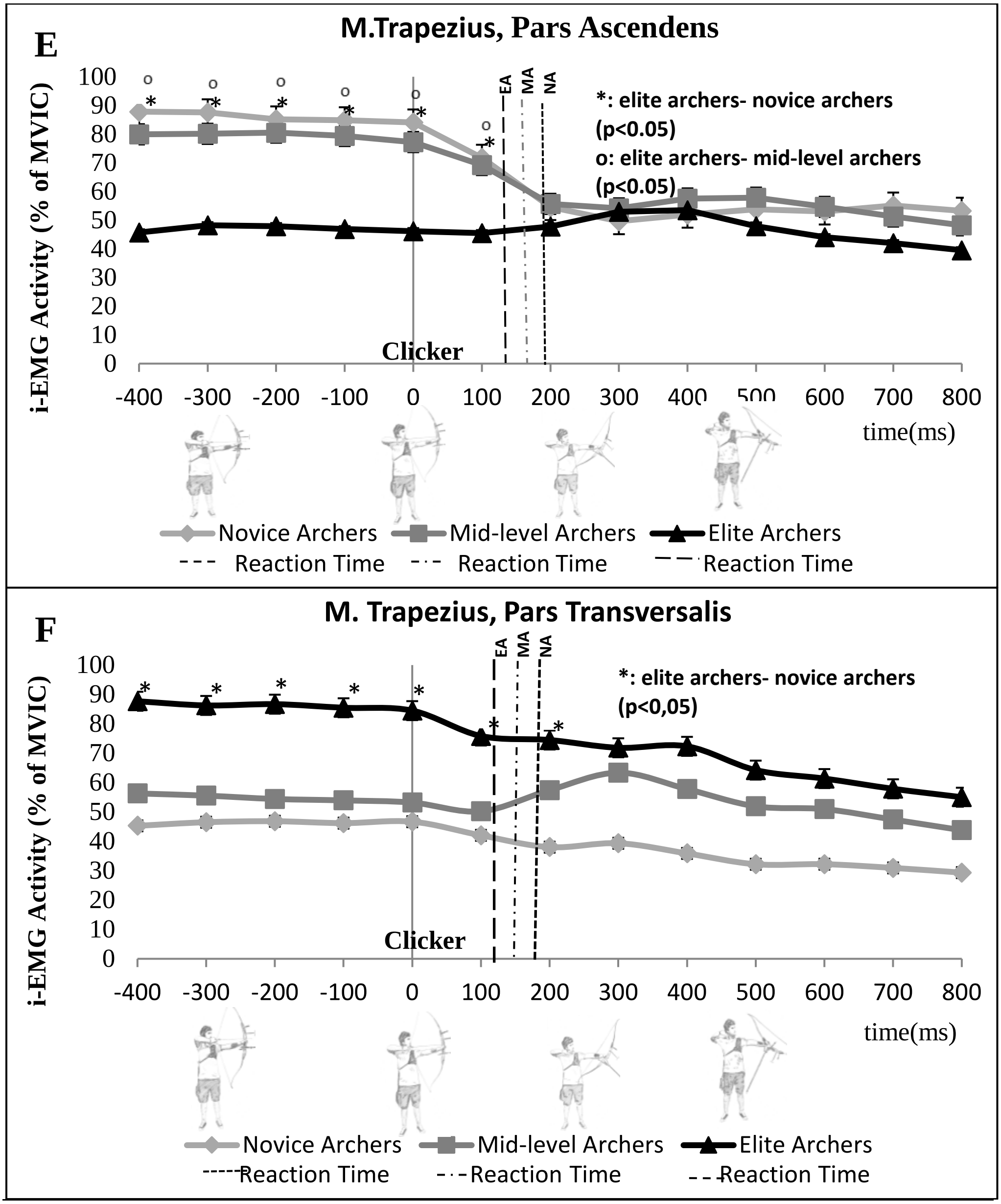


Figure 1 (A-F). **DRAWING ARM MUSCLE EMG VALUES OF ARCHERS WITH DIFFERENT LEVELS OF SKILL**

MDP muscle (Figure 1D)

The MDP EMG differed significantly ($p<0.05$) among the elite, mid-level and novice archers. MDP EMG activation in the elite group (80% of MVIC) was higher than that in the other groups (EMG activity of mid-level archers being 60% of MVIC; EMG activity of novice archers being 33% of MVIC) before the snap of the clicker. In the elite group, MDP relaxation (77% of MVIC) began just before the snap of the clicker. In contrast, MDP activation decreased just after the snap of the clicker for the novice and mid-level groups.

MTPT muscle (Figure 1E)

The MTPT EMG activities differed significantly ($p<0.05$) among the elite, mid-level and novice archers. MTPT EMG activation in the elite group (88% of MVIC) was higher than that in the other groups (EMG activity of mid-level archers was 56% of MVIC; EMG activity of novice archers was 45% of MVIC) before and after the snap of the clicker. However, the MTPT activation pattern of the novice archers was similar to that of the elite archers, but with a lower activation level. In contrast, MTPT EMG activation (63% of MVIC) in the mid-level archers increased just after the snap of the clicker.

MTPA muscle (Figure 1F)

The MTPA EMG activities also differed significantly ($p<0.05$) among the elite, mid-level and novice archers. MTPA EMG activation in the mid-level (80% of MVIC) and novice archers (88% of MVIC) was approximately two times higher than in the elite archers (46% of MVIC). The activation level of the lower trapezius muscles of the elite archers was static throughout the entire shooting test.

The EMG results indicated that the activation levels of MDA, MTPD and MPMPC were not significantly different among the groups ($p>0.05$).

DISCUSSION

The main purpose of this study was to compare the muscular activation strategies among archers with different levels of expertise. These assessments are of interest, particularly, in elite, mid-level and novice archers, because they allow the identification of different skill patterns and neuromuscular coordination related to training processes. The current study indicated differences between archers from different expertise levels in forearm, shoulder and selected back muscles. These differences were observed in the string, release phases and starting the follow through phase.

The study findings support the hypothesis because of significantly different EMG activities of the forearm flexor and extensor muscles among all proficiency levels of archery groups. There were different approaches of forearm muscle strategy that were proposed in previous studies (Martin *et al.,* 1990; Hennessey & Parker, 1990; Ertan *et al.,* 2005). Martin *et al.* (1990) who analysed the same muscular strategy and revealed that an archer should release the bowstring through a sudden relaxation of the muscles that maintain the flexed position of the fingers around the bowstring, rather than attempting to affect the release moment by willingly extending the fingers through concentric antagonistic muscle action. Similarly, findings of Ertan *et al.* (2005) showed that elite archers do not actively involve their extensor muscles in shooting, rather, they relax their flexor muscles during arrow release. Conversely, Hennessey and Parker (1990) explained the movement during string release as an active muscle contraction similar to flexion-extension.

In line with Hennessey and Parker (1990), previous research has identified m. extensor digitorum as the main muscle responsible for the string release movement (Nishizono *et al.* 1987). This muscular activity pattern was in accordance with the current study which indicates that all three groups demonstrate a sharp increase in M. Extensor Digitorum with different amplitude of activation during release phase. However, the activation pattern of the m. flexor digitorum in mid-level archers is different than other groups. To illustrate, mid-level archers demonstrated sharp increase in M. Flexor Digitorum in release phase, while activity pattern of this muscles was linearly decreased with different amplitude during the string release in novice and elite archers. A possible explanation could be attributed to a different approach of muscular contraction strategy/pattern, muscle group and differences in performance level.

The speed of the reaction to the fall (sound) of the clicker is directly related to the archer's performance (Ertan *et al.*, 1996). The reaction time to clicker was significantly different between novice and elite archers and occurred about 111ms after the fall of the clicker, whereas the release by beginners and mid-level archers took place about 140ms and 167ms after the fall of the clicker, respectively.

These findings reveal a positive effect of expertise on forearm muscular strategy in archery. Mid-level and novice archers displayed a preparation phase involving extensive extensor activity before the release of the bowstring. In order to react appropriately to the fall of the clicker, it is essential to develop a delicate coordination of M. Extensor Digitorum and M. Flexor Digitorum Superficialis which is called reciprocal inhibition. However, mid-level archers released the string by activating the finger flexors and actively involving the extensors co-contractly. Furthermore, mid-level archers demonstrated almost the same percentage MVIC of forearm muscles activation with elite archers before the snap of the clicker, but a sharper increase in the activation of the flexor digitorum muscle was observed just after arrow release.

In our study the forearm muscular activation pattern of the mid-level archers demonstrate co-contraction (abnormal force coupled relationships between extensors and flexors) which is not the intended situation for coordinated movement, such as archery shooting. Lateral deflection of the bow string engendered by undesired muscle co-contraction is one of the major causes of performance mitigation. Therefore, mid-level archers could have caused lateral deflection of the bowstring during the releasing phase because the movement of the active extension of the pull fingers reduces consistency in terms of shot-to-shot performance (McKinney & McKinney, 1997, Ertan *et al.*, 2011). This technical level can be improved with extended practice and repetition and the motor skills may become so well-learned that they can be carried out relatively automatically, with reduced effort and little attention to the details of the performance of the movement (Lang & Bastian, 2002; Wu *et al.*, 2004). However, no previous study on the effects of training on the decrease of co-activation values in archers was found in the literature.

Some studies have been conducted in other sports (Carson & Riek, 2001; Bazzucchi *et al.*, 2008; Wulf, 2008; Akito *et al.*, 2013) and their findings indicate a relationship between the degree of lower limb co-contraction movement achievement (skill level, training, etc.) and whole-body sensorimotor synchronisation movement. As the archer learns these processes after the training sessions, s/he will gain economic muscle coordination strategies by eliminating the unnecessary inhibition of muscular activation. Therefore, to master the technique described above, reciprocal inhibition could strengthen and decrease co-contraction during active movement. In elite archers, this allows them to focus on perfecting the techniques of shooting to obtain a stable aim and a consistent shooting performance (Era *et al*., 1996; Vuillerme & Nougier, 2004; Gautier *et al.*, 2006).

Motor skill level is also a possible explanation for the observed different activation pattern in novice level archers. In the beginning of learning the shooting skill, muscle activations involve incorrect performance because of increases in the amplitude of flexor muscles used to produce a shooting technique. Lay *et al*. (2002) explained that the learner consciously thinks about every part of the skill at the beginning of acquisition of the technique. The increased forearm muscle activation in novice archers is also a very important finding, because of the high number of repetitions performed during an archery competition, the shooting process should be highly repeatable.

Performing the repeatable shooting process makes forearm muscles highly contracted that leads to early fatigue. Pryimakov *et al.* (2015) explained that when the fatigue conditions occur, athletes increase amplitude and synchronism of the tremors of the various body links, therefore they cannot control their upright posture. This situation reduces the ability to dampen the vibrations and maintain the alignment of the shoulder girdle, as a result, archery shooting quality and scoring performance decreased for novice archers who fatigued earlier. Later, when the shooting technique is matured with practice, muscle activation becomes appropriate and the amount of conscious attention by the learner diminishes to a point where they perform the skill automatically, which reflects a reorganisation of the motor control system (Muratori, 2013). So that along with practising a complex skill, decreasing the energy cost and rate of perceived exertion, mechanical efficiency increases.

Regarding the muscle groups, most of the researchers have used forearm muscles for muscular coordination of movements associated with arrow release. Only a limited number of studies have focused on the activation of the shoulder and back muscles. In the current study, elite archers demonstrated higher MVIC% values in scapular and glenohumeral muscles, but not in the Trapezius Pars Ascendens. This mechanism was previously explained by Halder *et al.* (2001) and Kido *et al.* (2003). The deltoid muscle has been shown to passively affect the superior-inferior translation of the humeral head and limit anterior glenohumeral translation when the arm is abducted and externally rotated and, thus, is said to contribute to glenohumeral stability. Moreover, higher MVIC% values were observed during the main pulling phase, when the elite archers actively involved their posterior deltoid and middle trapezius muscles. This finding can be explained by the actions of muscles of the pulling arm.

The upper trapezius, middle trapezius and rhomboids demonstrate the dual action of rotating the cervical and upper thoracic spine to the left (towards the target) and stabilising the position of the right scapula relative to the thorax (Neumann, 2016). Furthermore, the upper and middle trapezius muscles simultaneously rotate the spinous process toward the scapula and stabilising the scapula against the pull of the long head of the triceps, posterior deltoid and serratus anterior (Rosso *et al.* 2014). In contrast, the current study indicated that the mid-level and novice archers generally relied on the lower trapezius muscle and moved the scapula to retract inferiorly. This could lead to disturbance in scapulohumeral rhythm (SHR). The three-dimensional pattern of integrated movement between glenohumeral scapulothoracic joint is known as the SHR, which allows the scapula to provide a stable base for glenohumeral movements and to be mobile to position the arm throughout its range of motion (Myers *et al*., 2005; Forte *et al*., 2009). For this reason, the SHR is assumed as a movement quality index of the shoulder complex. Therefore, based on these findings, emphasising appropriate scapular mobility and stability training should be suggested to non-elite level archers. Implementing scapular stabilisation exercises that incorporate lower extremity stability and muscle activation, would be appropriate.

CONCLUSION

The neurophysiological mechanism that underlies the EMG-related differences among the archery skill levels could be related to the motor skill learning phases of archers. Elite archers, who are at the last step of motor skill acquisition, demonstrate specific activation of the flexor and extensor muscles. Mid-level archers, who are at the association step of motor skill learning, simultaneously activate their flexor and extensor muscles by applying the co-activation strategy. During the full draw phase, the forearm extensor muscle activation strategy of mid-level archers is similar to that of novice archers, whereas their forearm flexor muscle activation strategy is similar to that of elite archers and archers advancing towards the upper levels.

Furthermore, mid-level archers’ activation of the posterior deltoid muscles is higher than that of novice archers, but lower than that of elite archers, and their back muscle use remains very low (nearly the same as that of novice archers) throughout all of the shooting phases. Novice archers, who are at the first step of motor skill learning, actively use their forearm flexors during the pulling step. To pull the string, upper-level archers use their distal muscles (MFDS, MED) less and their proximal (MDA, MDM, MDP) and axial muscles (MTPD, MTPT, MTPA) more, while mid-level and novice archers use their distal muscles more. This mechanism was interpreted as the most important factor affecting the horizontal oscillation of the string. More active use of the scapular and glenohumoral muscles and less active use of the hand and wrist muscles are thought to minimise the horizontal oscillation of the string.

RECOMMENDATIONS

The present study could serve as a reference point to pave the way for the development of effective archery training that include visual or audial feedback methods. Non-elite level archers should be taught how to use the passive flexor strategy and adapt related neural paths to score more points in archery. All in all, archers are encouraged to: (a) carry the pulling weight of string mainly with the axial and proximal muscles; (b) minimise the activation of the distal muscles; (c) strengthen isotonically the glenohumoral muscles and scapular motion and stability should be suggested.

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