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Quantification the relationship between FITA scores and EMG skill indexes in archery

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Abstract

Forearm electromyographic (EMG) data are assumed to be an effective method in estimating performance level in archery. The aim of the current study was to establish archery skill indexes based on EMG data. Elite ($n = 7$, FITA score = 1303.4 ± 26.2), beginner ($n = 6$, FITA score = 1152 ± 9.0) and non-archers ($n = 10$, assumed FITA score = 250 ± 0), were involved in the study. EMG activity of Muscle flexor digitorum superficialis and Muscle extensor digitorum were quantified. Two-second periods – 1 s before and 1 s after the fall of the clicker – were used to obtain averaged and rectified EMG data. The averaged and rectified EMG data were filtered by averaging finite impulse response filter with 40 ms time window and then normalized with respect to maximum voluntary contraction. To estimate FITA scores from EMG data, the following skill indexes that based on mean area under some parts of processed EMG waveforms was offered for archery. These were the pre-clicker archery skill index (PreCASI), post-clicker archery skill index (PostCASI), archery skill index (ASI) and post-clicker archery skill index 2 (PostCASI2).The correlations between rank of FITA scores and natural logarithms of archery skill indexes were significant for log(PreCASI): $r = -0.66$, $p < 0.0008$; for log(PostCASI): $r = -0.70$, $p < 0.0003$; for log(ASI): $r = -0.74$, $p < 0.0001$; log(PostCASI2): $r = -0.63$, $p < 0.002$. It is concluded that EMG skill indexes may be useful for: (a) assessing shooting techniques, (b) evaluation of archers' progress and (c) selection of talented archers.

Keywords: Archery; Electromyography; Muscular analysis and archery skill indexes

1. Introduction

Skill in archery is defined as the ability to shoot an arrow to a given target in a certain time span with accuracy [10]. Archery shooting is described as a three-phase movement as drawing, aiming and release [14]. Each of these phases represents a stable sequence of the collective movements and is ideal for studying the motor control and skill-acquired. An archer pushes the bow with an extended arm, which is statically held in the direction of the target, where the other arm exerts a dynamic pulling of the bowstring from the beginning of the drawing phase, until the release is dynamically executed [10]. The release phase must be well balanced and highly reproducible to achieve commendable results in an archery competition [14].

The bowstring is released when audible impetus is received from a device called "clicker". Each arrow can be drawn to the exact distance and a release can be obtained and maintained by this device. The clicker is reputed to improve the archer's score and is used by all target archers [10]. The archer should react to the clicker as quickly as possible and synchronize the muscle activity of the whole body to attain eventual

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optimal accuracy. In particular, there should be a repeated contraction and relaxation in the forearm and pull finger muscles during archery training and competitions according to the high number of arrows. When the clicker signal is heard, the archer relaxes the flexor group muscles of the forearm and actively contracts the extensor group muscles for producing the release. The archer should produce a muscular coordination between the forearm agonist and antagonist muscles [2,4,6,14].

Forearm muscles have special importance in holding and drawing the string by three-finger hook, taking it to full draw and releasing it. Importance of the activation patterns of the forearm muscles has been clarified and it is suggested that the archers, in different performance level, have different forearm contraction strategies. Elite and beginner archers displayed a stable contraction pattern before the clicker's impetus, while the non-archers showed a slight rising slope of contraction indicating an increase in the activity of the specified muscle groups before reaching the peak level [4].

Muscle co-activation is the simultaneous activity of various muscles acting around the joint. Evaluating the impact of skill level on the muscle activation/co-activation patterns is not a new topic [1,7,11]. The latency of antagonist EMG burst was strongly correlated with parameters of the first agonist EMG burst. For the movements described by the speed-insensitivity strategy, the quantity of both antagonist and agonist muscle activity can be uniformly associated with selected kinetic measures that incorporate muscle force–velocity relations. For movements collectively described by the speed-sensitivity strategy, no single rule can describe all the combinations of agonist–antagonist coordination that are used to perform these diverse tasks [5]. However, the question of whether an archer's performance level can be estimated by analyzing forearm EMG data is still unanswered. So, the aim of the current study was to quantify the relationship between some skill indexes and EMG measures by using linear regression.

2. Methods

2.1. Subjects

Three groups, (i) elite ($n = 7$, FITA score $= 1303.4 \pm 26.2$), (ii) beginners ($n = 6$, FITA score $= 1152 \pm 9.0$) and (iii) non-archers ($n = 10$, assumed FITA score $= 250 \pm 0$), were involved in the study. The FITA score is a summation of four distances (for female: 70, 60, 50 and 30 m; for male: 90, 70, 50 and 30 m), which are set by the International Archery Federation (FITA). An archer shoots 36 arrows to each distance. So, he/she shoots totally 144 arrows in a FITA round where the highest score can be 1440. The first group consisted of national team archers. Beginner archers from the city archery club formed the second group. The third group included university students with no background knowledge or experience on archery. The first and second groups had their FITA scores from official competitions. However, the non-archers group had not taken part any archery competition. To avoid the risks and dangers of non-archers' shoot, we did not have measured FITA scores for non-archers group. An interview was applied to four archery experts, who were working as national team coaches, for searching information about the highest score that a person who did not have any archery experience can shoot. They assigned 250 mean FITA score for a non-archer. Besides, the authors of this paper involved the students of a beginning archery class who had 8 weeks learning sessions to shoot a FITA round. These subjects had shot a mean of 288 FITA score (standard deviation 65). According to the findings of the interviews and the students' scores, the assignment of 250 was chosen as an appropriate FITA score for a beginner.

2.2. Electromyographic recordings

The measurement sites were prepared first by shaving the area and then lightly abrading and cleansing the skin with alcohol. Skin tack F55 circular Ag/AgCl surface electrodes, filled with conductive electrolyte, were then positioned longitudinally along each muscle. The center-to-center distance between two electrodes was approximately 2 cm. The reference electrode was placed on the olecranon process of the ulna of the drawing arm. The signals were pre-amplified (analog differential amplifiers, preamplifier gain 500), filtered using a bandpass filter (8–500 Hz), sampled at 1000 Hz, and converted in digital form by a 12 bit A/D converter.

Each subject participated in a single test session. EMG activity of the M. flexor digitorum superficialis (MFDS) and the M. extensor digitorum (MED) were quantified. Since MFDS and MED were surrounded by the other muscles closely, cross-talk effect may have been occurred during EMG measurements. It should be noted that the activity of flexors and extensors of the forearm measured as a whole in the current study. However, the EMG activities recorded from forearm muscles was named as activities of MFDS and MED for the sake of the specification of the mentioned finger movement pattern and referring to the recording sites. The surface electrodes were placed on the central portion of the each muscle. Palpating the selective muscles while subjects simulated the preparatory shooting position and performed maximum isometric contraction of these muscles recording sites on the drawing arm were identified.

2.3. Procedure

Forearm muscular activation strategies were evaluated from the EMG recordings immediately before and after the clicker's impetus. The arrow was initially positioned between the unattached end of the clicker and the bow-grip. As the arrow was pulled beyond the clicker, the clicker-lever fell on the bow-handle, which conveyed the signal to the archer that the arrow was appropriately positioned and is ready to be released.

A mechanical switch was attached under the clicker to accurately measure the point of the audible impetus. This audible impetus was superimposed with the EMG results in the same time frame. EMG recordings were for 5 s; 2.5 s prior and 2.5 s after the clicker's audible impetus. This time period included the last seconds of Full Draw, Aiming and the first seconds of Release and Follow Through phases. Two-second periods – 1 s before and 1 s after the fall of the clicker – were used to obtain averaged and rectified EMG data. The averaged [12] and rectified EMG data were filtered (averaging finite impulse response filter with 40 ms time window) and then normalized according to Clarys et al. [2].

Prior to the shootings, the maximum voluntary contraction (MVC) of the MED and MFDS of each subject were determined on the basis of EMGs. Subjects contracted these muscles to the highest level against a stable resistance by forming three-finger hook as they did in holding the bowstring and MVC was obtained under these circumstances. The angle between the proximal and distal interphalangeal joint was not changed during the isometric contractions of the mentioned muscle groups. EMG amplitudes were normalized with respect to MVC, i.e., they were expressed as percentages of MVC. By MVC normalization method, variations in the relationship could be found in the same muscle among subjects [3]. Figs. 1 and 2 show processed (averaged, rectified, filtered and normalized) EMG data for each group separately.

Each subject completed three trial shots to acquaint with the measurement conditions. Muscle activity was sampled for a 5-s period as the subjects completed 12 successive shots. After elimination of noisy ones, average of 8–12 single shots for each subject was used for calculations. For the shooting trials, the sampling was manually triggered shortly after the archer achieved a full (optimal) draw position, so that the release of the arrow occurred at approximately the midpoint of the sampling period.

2.4. Processing of skill indexes

To estimate FITA scores from EMG data, the following skill indexes was offered for archery: pre-clicker archery skill index (PreCASI), post-clicker archery skill index (PostCASI), archery skill index (ASI) and post-clicker archery skill index 2 (PostCASI2). For calculation of archery skill indexes, mean areas (area corresponding to time interval/the time interval) under the

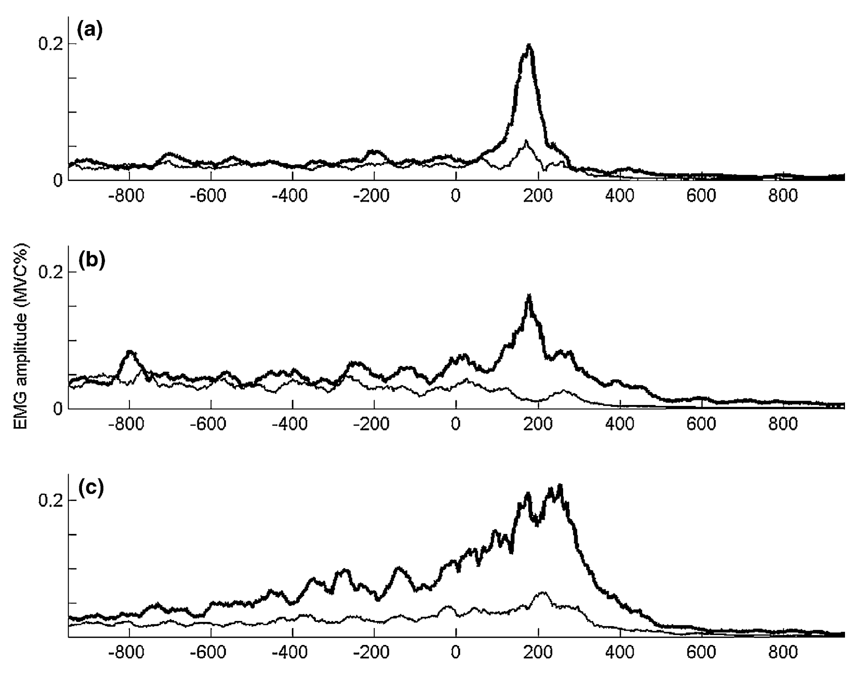

Fig. 1. Filtered and normalized EMG data (%MVC vs. ms): (a) average of elite archers, (b) average of beginner archers, (c) average of non-archers. Bold and thin lines correspond to MED and MFDS respectively. Clicker falls at zero.

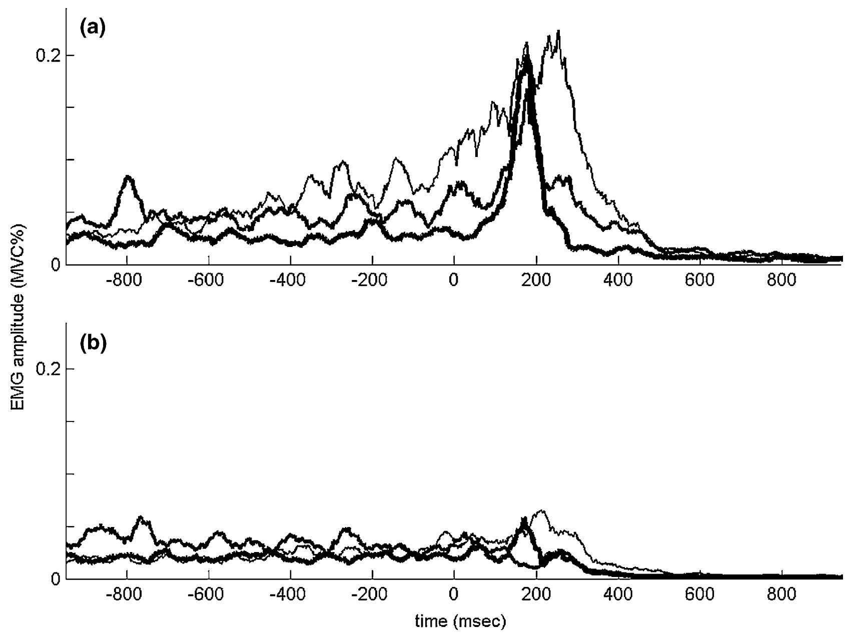

Fig. 2. The EMG data in Fig. 1 are regrouped (MVC% vs. ms): (a) MED, (b) MFDS. Bold, medium and thin lines correspond to elite, beginner and non-archers, respectively. Clicker falls at zero.

processed EMG data of MFDS and MED were used. Assuming clicker falls at 0th ms, mean areas under processed EMG data of MED were calculated: 300 ms continuous time interval (from −220 to +80 ms), 280 ms continuous time interval (from +160 to +440 ms) and 580 ms time interval (from −220 to +80 ms and from +160 to +440 ms) were accepted as PreCASI, PostCASI and ASI respectively. Mean area, 200 ms continuous time interval (from +240 to +440 ms), under processed EMG data of MFDS was also calculated as PostCASI2. Selection of time intervals was based on maximisation of square of correlation coefficients (r^2) between the rank of the FITA scores and archery skill indexes. This maximisation gave four different archery skill indexes' time intervals and the relationship between rank of FITA scores and natural logarithms of skill indexes (log(PreCASI), log(PostCASI), log(ASI) and log(PostCASI2)) were calculated using regression analysis (Fig. 3).

3. Results

Results of Kolmogorov–Smirnov test showed non-normal distribution for FITA scores, so rank of FITA scores were used in regression analysis by assigning rank numbers from 1 to 23 to every member of ascending ordered FITA scores. If there were ties, rank of equal FITA scores was replaced by mean rank values. Since the relations between rank of FITA scores and archery skill indexes were found exponential, natural logarithms of indexes were used for making the relations linear and increasing estimation accuracy.

The correlations between rank of FITA scores and log of archery skill indexes were significant for log(PreCASI): $r = -0.66$, y-intercept = −5.43, gradient = −6.05, $n = 23$, $p < 0.0008$; for log(PostCASI): $r = -0.70$, y-intercept = −3.40, gradient = −4.96, $n = 23$, $p < 0.0003$; for log(ASI): $r = -0.74$, y-intercept = −7.70, gradient = −6.72, $n = 23$, $p < 0.0001$; log(PostCASI2): $r = -0.63$, y-intercept = −9.57, gradient = −4.38, $n = 23$, $p < 0.002$. See Fig. 3 for regression lines.

4. Discussion

Archery shooting is described as a three-phase (drawing, aiming and release) movement. Moreover, Nishizono et al. [14] further divides the stages of a shot into six: bow hold, drawing, full draw, aiming, release and follow-through. PreCASI (300 ms continuous time interval from −220 to +80 ms) corresponds with the full draw, aiming and release movements. PostCASI (280 ms continuous time interval from +160 to +440 ms) includes the initiation of the response to fall of the clicker. So, the second index covers the release, which is the beginning of the response to a given stimulus (fall of the clicker), and the follow-through, which is the completion of the specific movement pattern or muscle contraction, phases. 200-ms continuous time interval from +240 to +440 ms under processed EMG data of MFDS was also calculated as PostCASI2. It is mainly related with the completion of muscular activity or the changes in the position in metacarpophalangeal, proximal and distal interphalangeal joints. ASI (580 ms time interval: from

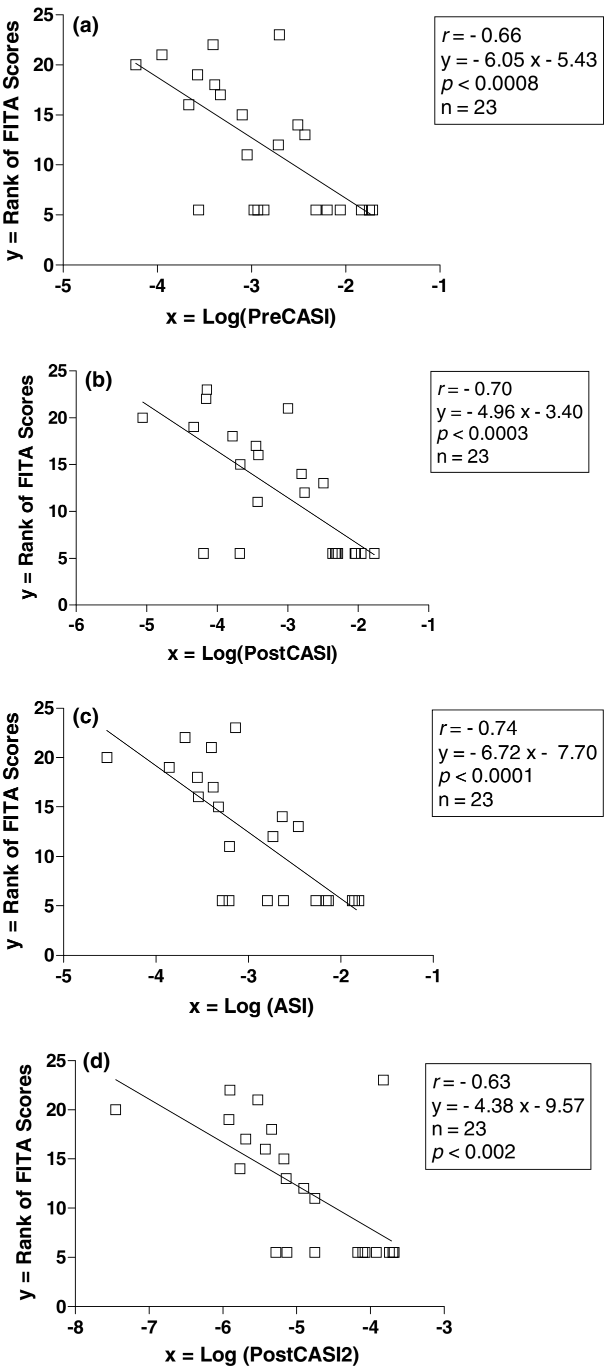

Fig. 3. Relationship between rank of FITA scores and natural logarithms of PreCASI (a), PostCASI (b), ASI (c) and PostCASI2 (d). Regression parameters and lines are shown on the graphs.

−220 to +80 ms and from +160 to +440 ms) is the weighted sum of PreCASI and PostCASI. It includes the fore period before the fall of the clicker, premotor and motor times, which is the time gap that the impulse is transmitted from the sensory organs to the central nervous system and then to the muscles [9]. The interval from the stimulus to the first muscular contraction recorded in EMG is termed premotor Reaction Time and is thought to represent the central nervous system processes. This index also covers the interval from the first change in EMG to finger movement, which is termed motor Reaction Time and represents the processes associated with the muscle itself [8,9,15–17]. The interval from the initiation of the response (the end of Reaction Time) to the completion of the movement is also involved in ASI. The archery indexes summarize the whole archery shooting movement. They separate the muscular activation into small but meaningful pieces. They provide information on the whole muscular activation patterns before and after the fall of the clicker.

Archery shooting has a stable sequence and it includes the stance, holding, drawing, full drawing, aiming, releasing and follow-through movements. Each of these phases represents a stable sequence of the collective movements.An archer is supposed to hold the string by three-finger hook in the drawing hand [13]. Forming three-finger hook is an example of isometric contraction. So, the archer should not change the angels of the drawing fingers or proximal and distal interphalangeal joint until the release. Increasing or decreasing areas under the processed EMG data may be an indication of the changes in phalangeal joint angles before the fall of the clicker. That can be the reason why the rank of FITA scores has negative correlation with EMG activities. The archer tries to hold and carry the weight of the string by contracting the forearm muscles. On the contrary, a decrease in EMG activities in the forearm muscles indicates that the archer may disperse the weight of the string on the forearm, arm, shoulder girdle, and some of the back muscles. So, the percentage of the forearm muscles decreases in the collective archery shooting movement.

Having negative significant correlation between rank of FITA scores and log of archery skill indexes shows that increase in archery experience causes a decrease in area under the processed EMG data. The amplitude of the peak (Fig. 2(a), amplitude of peak around 260 ms) after the fall of the clicker is also decreases in line with the increase in archery experience.

The proposed archery skill indexes summarize the archery shooting movement from beginning to the end. They involve and describe all of the shooting phases from the drawing hand aspect. Moreover, they expose a negative relationship between the forearm muscular activation and FITA scores. EMG skill indexes may be helpful evidences during the construction and trying out of new shooting techniques in archery in such a way that revision of the shooting technique can be based on this evidence. They seek specific information about the shooting technique as well as judgements or opinions of a coach, who can make only visual inspection of the technique. Those archery indexes and judgements by the archery coach together may serve as feedback for FITA score or in general performance improvement. EMG skill indexes may be useful for assessing shooting techniques while they are being developed, to help shape them in their final forms. This may be applicable to all sorts of archery performance level (e.g., beginning or elementary level; national level; or world-class archer). It is concluded that EMG skill indexes may be useful for: (a) assessing shooting techniques, (b) evaluation of archers' progress and (c) selection of talented archers.

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