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Archery performance level and repeatability of event-related EMG

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Abstract

The purpose of the current study was to compare the repeatability of electromyographic linear envelopes (LE) of archery groups. Surface electromyography (EMG) signals of musculus flexor digitorum superficialis (MFDS) and extensor digitorum (MED) of 23 participants (seven skilled, six beginner archers and ten non-archers) were recorded during archery shooting. Two-second periods (clicker falls at first second) of 12 shots' EMG data were recorded, full-wave rectified and filtered (60 ms moving-average filter) for each participant's drawing arm. Repeatability was investigated by using a statistical criterion, variance ratio (VR). Archers' performances were evaluated in terms of FITA scores. The results showed that FITA scores were significantly correlated to the VRs of MFDS and MED. EMG LEs were more repeatable among archers than non-archers. Therefore, we inferred that VRs of MFDS and MED might be important variables for (a) assessing shooting techniques, (b) evaluation of archers' progress, and (c) selection of talented archers.

PsycINFO classification: 3720

Keywords: Archery; Electromyography; Repeatability; Performance; Variance ratio

1. Introduction

Archery is described as a static sport requiring strength and endurance of the upper body, in particular the shoulder girdle (Ertan, Kentel, Tumer, & Korkusuz, 2003; Mann,

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1994; Mann & Littke, 1989; Martin, Siler, & Hoffman, 1990). High performance shooting in archery is defined as the ability to shoot an arrow at a given target with accuracy (Ertan, Soylu, & Korkusuz, 2005; Leroyer, Hoecke, & Helal, 1993; Martin et al., 1990). In the literature, some of the researchers describe the shot as a three-phase movement: the stance, the arming, and the sighting (Leroyer et al., 1993; Martin et al., 1990; Pekalski, 1990). Alternatively, Nishizono, Shibayama, Izuta, and Saito (1987) divide the shot into six stages: bow hold, drawing, full draw, aiming, release, and follow through. Each of these phases represents a stable sequence of the entire movement. Thus, the task of an arrow shot starts with holding and ends with release or follow-through movements.

During the drawing phase, an archer pushes the bow with extended arm and pulls the bowstring with the other arm. He/she places the bowstring on his/her face (the tip of the nose, the lips, and the chin) for reaching the final position of the drawing phase. In the full draw position, the archer has to perform many tasks simultaneously. He/she should both aim at the target and release the bowstring without disturbing the aiming position and the lateral deflection of the string. Therefore, the release phase must be well balanced and highly reproducible to achieve commendable results in an archery competition (Açıkada, Ertan, & Tınazcı, 2004; Keast & Elliot, 1990; Landers et al., 1992; Landers, Wang, & Courtet, 1985; Leroyer et al., 1993; Martin et al., 1990; Stuart & Atha, 1990).

Releasing the bowstring requires the use of small muscle groups to accomplish the shooting, particularly the coordinated actions of the flexors and extensors of the fingers of the arm responsible for drawing, holding and releasing the bowstring. The archer is supposed to react to an auditory stimulus from the fall of the clicker by coordinating the forearm muscles. He/she contracts the extensor and relaxes the flexor muscles in the forearm to release the bowstring accurately (Ertan et al., 2003). In this way, the archer can produce a pull–push balance between the drawing and the bow arm, and perform a consistent release of the bowstring (Nishizono et al., 1987).

Pulling the bowstring by drawing the arm includes the elbow flexed by concentric contraction of biceps brachii and brachialis muscles, while the shoulder is extended by the strong concentric action of teres major, latissimus dorsi and posterior fibres of deltoid. The pectoral girdle is protected by concentric shortening of trapezius, rhomboid major and rhomboid minor. During the pushing movement of the bow by abduction and flexion of the shoulder, the shoulder is maintained in abduction by isometric contraction of the middle fibres of deltoid, and is then rapidly flexed by the anterior fibres of deltoid and pectoralis major, assisted by coracobrachialis and long head of biceps, all of which work concentrically (Palastanga, Field, & Soames, 2002). When we consider the collective movement of archery shooting, the bow arm is responsible for pushing the bow and adjusting the placement of the sight on the target by resisting the force from the drawing arm (Nishizono, Nakagava, Suda, & Saito, 1984).

If a skilled archer uses a particular strategy for his/her best shooting, i.e., of the kind described in the preceding, can he/she repeat the same strategy? Assuming that surface electromyography (EMG) is a good representative of that strategy, can it be verified with surface EMG? Answers to these questions may provide important results for assessing the shooting techniques, the evaluation of the archers' progress, and objective selection of talented archers.

The purpose of the present study was to compare the repeatability of electromyographic linear envelopes (LE) of archery groups. Surface EMGs of participants were recorded during archery shooting. Previous Federation Internationale de Tirà l'Arc (FITA) scores of archers were assumed to be good representatives of archery performance level and repeatability was measured with variance ratio of the EMG LEs (Hershler & Milner, 1978).

Although it takes months or years to take part in a national/international tournament for a newcomer archer, one of the best measures of archery performance level is archer's FITA score. Since it is measured in the tournaments that are governed by the International Archery Association, FITA, Ertan et al. (2003, 2005) used FITA score as an indicator of archery performance level because of its objectivity and international acceptance.

If FITA scores and repeatability of EMG linear envelops do not show a statistically significant relation, it may be attributed to muscle fatigue. Power spectral density (PSD) analysis of surface EMG can be used for muscle fatigue determination since muscle fatigue accompanies changes in the power spectrum of EMG such that a decline in median frequencies (MF) can be used to monitor fatigue (Arendt-Nielsen & Sinkjaer, 1991; Christensen, Sogaard, Jensen, Finsen, & Sjogaard, 1995; Horita & Ishiko, 1987; Potvin & Bent, 1997; Sundelin & Hagberg, 1992).

2. Methods

2.1. Participants

Three archer groups, (i) elite ($n = 7$, FITA score $= 1303.4 \pm 26.2$ ($M \pm$ SD)), (ii) beginners ($n = 6$, FITA score $= 1152 \pm 9.0$) and (iii) non-archers ($n = 10$, assumed FITA score $= 250 \pm 0$) participated in the study. The FITA scores (Ertan et al., 2005) were used for classifications of archers as elite, beginners and non-archers, from higher to lower performance level.

2.2. EMG measurement

In the present study, we used the same EMG recordings as in our previous work (Ertan et al., 2005), which we therefore describe only briefly here. Ag/AgCl electrodes with a center-to-center distance of 2 cm were placed longitudinally along each muscle. The electrodes were placed on the muscle belly and its positive and negative electrodes were positioned parallel to the muscle fibres of m. flexor digitorum superficialis (MFDS) and m. extensor digitorum (MED). During the piloting of the current study, several sites for placement of the reference electrode were explored (e.g., cervical notch of sternum, acromion process of scapula and olecranon process of ulna). The reference electrode was finally placed on the olecranon process of the ulna, which was found to be a relatively neutral site (Janson, Archer, & Norlander, 2003) and suitable for archery shooting as it did not disturb the archer during the shots. Bortec Octopus EMG system (AMT-8) was used in the study. Analog signals were digitized by a 12-bit A/D converter. Pass band of the EMG amplifier, sampling rate, maximum intra-electrode impedance and CMMR were 8–500 Hz, 1000 Hz, 6 kΩ and 95 dB, respectively. We did not use any notch filter.

Each participant engaged in a single test session involving 15 shots, the first three being warm-up shots. EMG activities of MFDS and MED were quantified. Although cross talks of forearm muscles' EMG activity exist, we will accept the EMG activity of MFDS (or MED) as recorded from MFDS (or MED) itself for simplification. Two-second periods of twelve shots' EMG data were full-wave rectified and filtered (moving average filter with 60 ms time-window) for each participant. Nine hundred to 1500 ms time window of rectified and filtered EMG (i.e., EMG LE) was used for repeatability measurement (clicker falls at time = 1 s).

2.3. Calculation of variance ratio (VR) and statistical analysis

The VR as proposed by Hershler and Milner (1978) quantifies repeatability of waveforms and it was successfully used in gait analysis (Granata, Padua, & Abel, 2005; Kadaba, Wootten, Gainey, & Cochran, 1985). Following equation of VR measures similarity of EMG signals, in which 0 indicates exactly the same waveforms (no variability or maximum repeatability), 1 corresponds to dissimilarity of waveforms (maximum variability or no repeatability), and other values lie between 0 and 1.

$$\mathrm{VR} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(E_{ij} - \bar{E}_i)^2/m(n-1)}{\sum_{i=1}^{m}\sum_{j=1}^{n}(E_{ij} - \bar{E})^2/(mn-1)}$$

where m is the number of temporal points; n is the number of EMG signals; E_{ij} is the value of the jth EMG signal at time epoch i; $\bar{E}_i$ is the value of averaged EMG waveforms at time epoch i and $\bar{E} = \frac{1}{m}\sum_{i=1}^{m}\bar{E}_i$. VR as a measure of EMG LE repeatability is mathematically simple, intuitive and a practically proven method (Granata et al., 2005; Hershler & Milner, 1978; Kadaba et al., 1985).

Spearman correlation was used to analyze the relationship between FITA scores and the VRs in view of the non-normal distribution of FITA scores (Ertan et al., 2005). Kruskal–Wallis test was used for participant's VRs vs. skill groups (elite, beginner and non-archer) as Bartlett's test (Netter, Kutner, Nachtsheim, & Wasserman, 1996) suggested that the differences between standard deviations were significant ($p < .05$). Dunn's multiple comparisons test was used for post-tests. Time interval, ranging from 900 to 1500 ms, of EMG LEs was selected for repeatability measurement.

To examine the effect of muscle fatigue on the VRs, muscle fatigues of MED and MFDS were calculated for the first and last shots of each archer, by using median frequencies (MF) of PSDs. Two seconds of the raw data of each archer were divided into four 500 ms consecutive regions for every shot. A fast Fourier transformation (FFT) of 4096 samples was used to perform a spectral analysis over each 500 ms interval. Student's t-test was used for the comparison of MFs.

3. Results

Significant correlations (Spearman) were found between the FITA scores and the VRs (for VR of MED, $r = -.72$, $p < .0002$; for VR of MFDS, $r = -.72$, $p < .0003$). Variation among group medians of VRs was significant ($p < .002$) for both the MED and MFDS. Dunn's multiple comparisons post-test showed that the elite archers' median of the VRs for MED was significantly lower ($p < .001$) than the non-archers'. Dunn's test also showed that the archery groups' medians of the VRs for MFDS were significantly lower ($p < .05$) than the non-archers'. Fig. 1 shows some archers' EMG LEs and corresponding VRs. VRs of groups are shown in Fig. 2.

There were no statistically significant differences between mean MFs of the first ($M = 115.6$ Hz, SD = 20.4 Hz) and last ($M = 106.2$ Hz, SD = 21.7 Hz) shots for all muscles and time intervals.

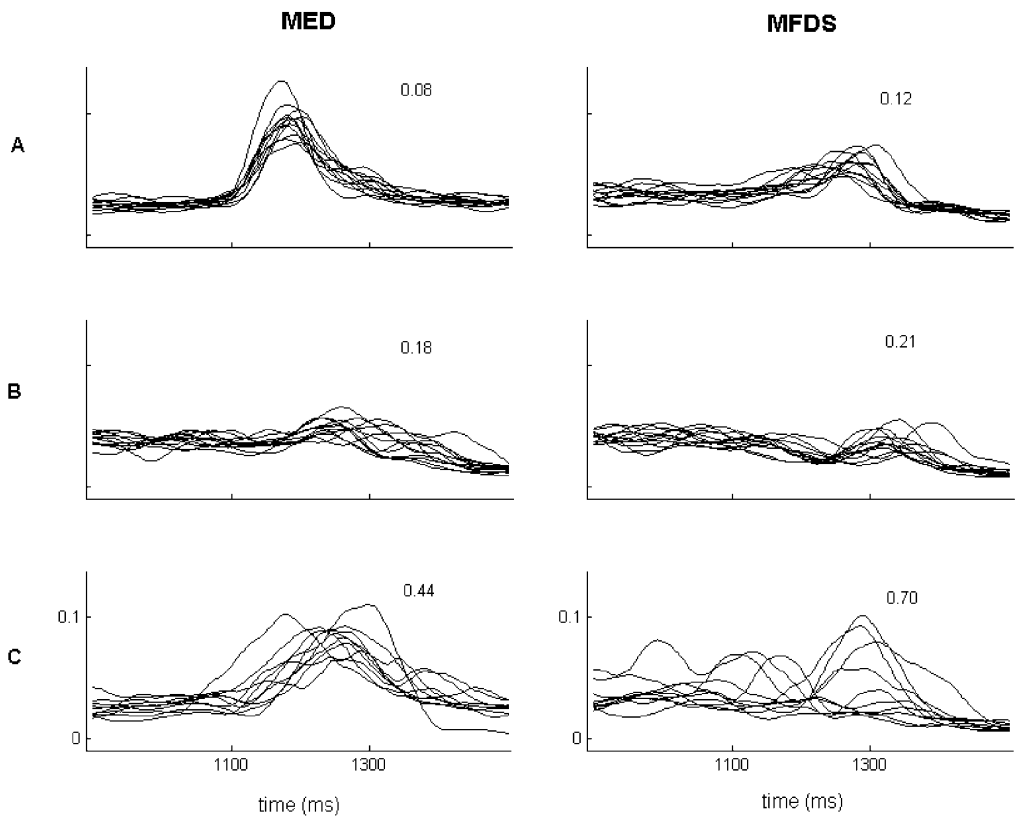

Fig. 1. Normalized EMG linear envelope (unit less) versus time graphs for an elite (A), a beginner (B) and a non-archer (C). VRs are shown on the upper-right corner of corresponding graphs. Normalization was performed by multiplying each linear envelope with a scalar so that normalized linear envelope's sum-square ($\sum_{k=1}^{n} X_k^2$) becomes unity. Clicker falls at 1000th ms. Aim for the normalization is to expand figures for visual comparison.

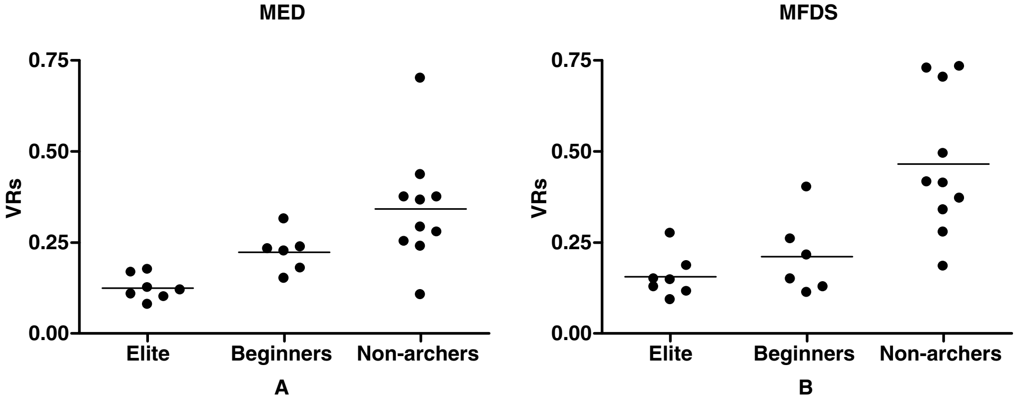

Fig. 2. VRs of archer groups for MED and MFDS. Horizontal lines show mean values of groups.

4. Discussion

In this study, we addressed the following question: do archers with higher performance levels also have higher EMG LE repeatability? While examinations of Figs. 1 and 2 hint at possible answers to this question, statistical analysis of the data proves that: (i) the archers' EMG LEs are more repeatable than the non-archers', (ii) significant correlations exist between FITA scores and VRs. Fatigue is excluded as a likely potential confounding factor. Therefore, the answer to the above question is "yes".

The selection of some parameters (time interval of EMG LEs for repeatability measurement, window length of moving average filter) in our study requires some explanation. Since EMG recordings are time-locked to the event of clicker's fall (i.e., they were recorded in fixed time-relation to the event), we will call them event-related (ER) EMG records. The time interval from 900 to 1500 ms of ER EMG data was selected because it includes the full-draw and the aiming phases before release and the follow-through phases just after the clicker's fall (Ertan et al., 2003; Nishizono et al., 1987). Sixty ms of window length for moving average filter was used and increasing window length did not change statistical results significantly as in Kadaba et al.'s (1985) study.

Clarys et al. (1990) examined arrow speed, repeatability of arrow speed, arrow precision and repeatability of iEMG for archery groups (six beginners, six national and three Olympic archers) in some parts of their extensive study. They recorded surface EMGs of ten muscles, including drawing arm's MED and MFDS. The Olympic archers' iEMG repeatability was higher than that of the national and beginner archers ($p < .01$) for MED and some other muscles. Our study largely supports Clarys et al.'s (1990) results about the repeatability of EMG, although some differences (number of participants, classification of participants, measuring method of EMG similarity, statistical method and control of fatigue in beginner archers) exist.

The center of the target is counted as the highest score (10) for the recurve bow category. The distortion of the arrow-hit from the center of the target is considered a sign of change in both the shooting technique and/or the equipment tuning. FITA score, which is achieved by adding up the 144 shots together, is a general outcome of the collective shooting technique with a certain equipment adjustment in relation to the weather conditions during the time of shooting. Therefore, the detection of the reason(s) of arrow distortion from the center of the target would not be possible by only analyzing the FITA scores. FITA score only supplies summative information about the whole shot in archery. Hence, it will help us to decide whether the training program or any of its parts should be revised, continued or terminated. It provides information on the product's efficacy and it is typically quantitative, using numeric scores to assess archer's achievement. On the other hand, someone may need some formative information, which is typically conducted during the development or the improvement of the shooting technique, equipment adjustment or product (FITA score) for in-house evaluation of the performance level with the intention to improve. From this point of view, ER EMG data may supply a formative type of evaluation of the shooting technique by comparing the summative FITA score with the formative forearm muscular activity.

ER EMG summarize archery-shooting movement from beginning to the end in terms of the drawing hand aspect and may give specific information about the shooting technique in relation to FITA score as well as the judgments or opinions of a coach, who can only make visual inspection of the technique. Those ER EMG data and observations of archery coach may serve as feedback for FITA score, which can be considered as performance and/or the outcome of archery shooting (FITA score). Besides, ER EMG data may be useful for assessing the shooting techniques while they are being developed, to help shape them in their final forms. It signifies part of the archery performance. Based on the findings of our study, we infer that the offered similarity measures might be used as suitable variables for assessing shooting techniques, evaluation of archers' progress, and selection of talented archers.

The following results reveal limitations in the usage of the VRs. First, the maximum correlation presented in the current study explains only 52% ($r = -.72$) variation of FITA scores, which indicates that we cannot explain the main possible reasons of arrow distortion by only analyzing the forearm muscular activity. Second, although the VRs are acceptable for group comparisons as in this study, it is not useful for individual evaluation. Nevertheless, if justified by further studies, increasing the number of the shoots performed by each archer may overcome this limitation.

This study elaborated on intra-archer EMG LE repeatability as a function of the three identified groups (elite, beginners and non-archers) and their FITA score. It appears that the order of the repeatability decreases from elite group to non-archers.

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