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Shooting dynamics in archery: A multidimensional analysis from drawing to releasing in male archers

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Abstract

The purpose of this study is to investigate the relationships between physiological and mechanical dynamics during arrow releasing in archery with the quality of the arrow shot. Four elite male archers were involved in this study. Mechanical clicker reaction time (MCRT), Integrated Electromygraphic % (IEMG %) activity of hand flexor and extensor, deltoid and trapezius were recorded at a sampling frequency of 600 Hz. Aiming behaviours, aiming time, total drawing time (TDT) and full drawing time (FDT) were calculated by the first act in trapezius. Postural sway, aiming sway and body weight shifts, changes in the posture of archers toward sideways (DX) and front-back (DY), decrease in the body weight (DBW) on legs were recorded at the same sampling rate using force plates for every arrow of archers. All the measurement methods were synchronized with each other and referenced to the clicker fall. Subjects completed 30 arrows on an 18m range constructed indoors. Statistical analysis was conducted using SPSS 12.0. It has been found that performance of male archers varies according to flexor muscle one second prior to clicker falls and that the performance increases when the muscular activity of flexor and deltoid muscles decreases. It has been stated that archers have better shots as the posture sways towards right-left within the period of holding the bow tight and as the drawing time decreases. In conclusion, archers MCRT is shorter for high performance. As muscle activity decreases, performance increases. Aiming sways on the target towards right-left, up and down and postural sways during releasing towards sideways and anterio-posterior affect performance. Drawing time may change with performance and which is affected by shift in the body weight especially after releasing.

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Keywords: Muscular analysis; centre of pressure; reaction time; Electromyography (EMG)

1. Introduction

Shooting in archery can be summarized as drawing the bow, aiming and releasing [1]. Archery can be described as a comparatively static sport requiring strength and endurance of the upper body, in particular the forearm and shoulder girdle [2]. An archer pushes the bow with an extended arm, which is statically held in the direction of the target, while the other arm exerts a dynamic pulling of the bowstring from the

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beginning of the drawing phase, until the release is dynamically executed [3]. The bowstring is released when an auditory stimulus is received from the “clicker”. A coach or the archer can standardize the equipment factors by having exactly the same size and weight arrows and using the “clicker” device to fix the drawing weight of the bow constant. A standard drawing length and release can be obtained using this device [4, 5]. After release the position of the arrow on the target determines the performance.

There are not many studies related to archery analyzing the reaction of an archer to the fall of the clicker. The effect of reaction time on scoring points in archery can be one of the major research topics where the main idea is to search for any relationship between the time of reaction and the scored points on the target in archery. Ertan [6] conducted research on archers to demonstrate the effect of clicker reaction time on scoring points. He included 8 male and 8 male high level archers’ in his study. Analysis showed that there was no correlation between the clicker reaction time and the scored points in both group of archers.

Thus, the aim of this study was to examine some physiological and mechanical dynamics in shooting, simultaneously with reference to clicker fall and analyse the changes according to the scores.

2. Methods

2.1 Subjects

Four elite male archers were involved in this study. They had represented or were representing Turkey in world and/or national events. Archer’s ages, body weights, heights and drawing weights are presented in Table 1. All archers were right-handed and recurve bows were used in this study.

Table 1. Physical characteristics of male archers (n=4)

Age (year)	25.7 (3.7)
Body Weight (kg)	54.0 (2.8)
Height (cm)	168 (3.5)
Drawing weight (kg)	16.9 (0.1)

2.2 Muscle activity recording

To measure electrical activity in the forearm muscles (Flexor digitorum superficialis, extensor digitorum), deltoid and trapezius by means of EMG (surface EMG techniques) [5 - 10], a TMREMG Analog Multiplexed cable Telemetry 8 channel device was used. The electrodes were placed at the geometrical centre as stated in the literature [8]. Prior to the shootings the maximum voluntary contraction (MVC) of the M. extensor digitorum (opposite direction), trapezius, posterior deltoid and M. flexor digitorum superficialis of each subject were determined on the basis of EMGs. EMG amplitudes were normalized with respect to MVC, i.e. they were expressed as percentages of MVC (100%) [7]. Using these normalized iEMG values, means and standard deviations for the 30 shots (3 x 10) of each subject were then calculated. The EMG was measured on the draw arm. EMG recordings were averaged over fifteen second. This time period included the last seconds of full draw, aiming and the first milliseconds 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 the rectified EMG data. The data were than averaged across 100 ms intervals and the amplitudes were normalized. In all circumstances, the M. trapezius showed the earliest contraction both in the draw-arm (as stated by the Clarys *et al.* [7]), so during the analysis of muscle activities, the first act of trapezius muscle until the clicker falls was named total drawing time (TDT) and when the trapezius muscle reached max IEMG % (integrated activation percentage of muscle) until the clicker falls was named full drawing time (FDT).

2.3 Force plates

All force data were recorded using Prosport Force platforms. The centre of the target was placed directly in line with the midline drawn parallel to the long axis of the platform so that the Ax direction represented lateral movements (DX) and the Ay direction represented anterior posterior movements (DY) [9]. The position of the feet was then marked and they were told to ensure that this position was kept throughout the recording session [9 - 11]. Postural sway differences of archers were examined as the body mass changes between the total drawing until the clicker falls, represented as DX for side to side sway (parallel to the target face) and DY for anterior-posterior (sway perpendicular to the target face). Body mass differences on both legs especially after the clicker fall (DBW) were also calculated. Force plates reliability and validity was high ($r = 0.98$).

2.4 Aiming time and sways

The aim process can be recalled in real time and analyzed. Rika Home Trainer mainly aims to measure/observe; movements of archers during aiming towards right-left (Rx) and up-down (Ry) on the target and the time (Rt) on the target. This device has 3 different parts. The characteristics of the 3 different parts are; Connector Unit, Sender Unit and Control Panel. The system is on the working position as a result of the interaction of these 3 units with each other and with its serial port RS 232 connection to the computer. Before each shooting, it was calibrated according to the manufacturer's instructions [12]. The system starts recording, when the sender unit (which was attached on the bow) was still on the target more than 0.1s.

2.5 Mechanical clicker reaction timer

A Prosport TMRESC 3100 archery chronometer was used, which has been designed to measure clicker mechanical reaction time of archer (MCRT). The device can make the measurement with 0.001 second sensitivity and 0.01% error [5]. The reliability and validity of archery chronometer was found to be high ($r = 0.98$, $p < 0.05$). The bowstring is released when an auditory stimulus is received from the clicker. The time gap between the stimulus and releasing bow is called mechanical clicker reaction time (MCRT).

2.6 Statistical analysis

Statistical Analysis was conducted using SPSS 12.0, using a correlation analysis, ANOVA and T-test. Also Bonferroni adjustment was conducted on all ANOVA results. The results were reported as mean ± standard deviation. Statistical significance was set at $p < 0.05$.

3. Results

Comparison and correlation of male archers IEMG % muscle activities and MCRT one second before and after the fall of the clicker have been presented as poor (8), good (9) and very good (10) scores as is shown in Table 2.

Table 2. Muscle activities one second prior to and after the clicker falls and MCRT values of archers.

Score	8 n=34	9 n=35	10 n=39	F	n=108 r
MCRT (ms)	143.4 (18.6)	142.5 (15.8)	142.3 (14.4)	.05	-.029
F^1 %	85.6 (6.9)	84.4 (7.3)	80.0 (8.8)	5.4*	-.292*
F^2 %	33.1 (7.4)	34.9 (7.8)	32.0 (5.9)	1.5	-.069
D^1 %	87.0 (6.0)	84.0 (6.0)	85.4 (7.1)	1.1	-.079
D^2 %	31.6 (3.2)	30.6 (4.2)	29.7 (3.6)	2.4	-.211*
T^1 %	74.3 (10.7)	73.3 (10.3)	70.0 (8.8)	1.8	-.178
T^2 %	70.6 (16.8)	74.8 (9.1)	73.2 (9.4)	1.0	.082
E^1 %	83.8 (8.0)	81.3 (7.7)	82.3 (8.4)	.86	-.072
E^2 %	58.9 (15.1)	60.0 (10.1)	54.5 (10.7)	2.1	-.151

%: MVC (maximum voluntary contraction)
F (flexor), D (deltoid), T (trapezius), E (extensor)^1: One second before clicker fall
F (flexor), D (deltoid), T (trapezius), E (extensor)^2: One second after clicker fall
*$p < 0.05$

MVC mean F^1 was significantly lower in the very good score (10) than in good and poor scores and had significantly negative correlation with the other scores (see Table 2).

Table 3. Male archers' postural sway differences between the total drawing time and until the clicker falls are represented as DX for left to right and DY for anterior-posterior and velocity, aiming sways (Rx, Ry) and time (Rt) during targeting .

Score	8 n=34	9 n=35	10 n=39	F	n=108 r
DX (mm)	31.7 (1.0)	12.5 (4.5)	16.7 (1.0)	2.8	.224*
DY (mm)	26.2 (1.5)	5.1 (1.3)	4.5 (0.4)	1.0	.140
XV (mm/s)	5.0 (0.1)	2.3 (0.8)	4.3 (0.2)	2.2	.198*
YV (mm/s)	4.7 (0.2)	1.1 (0.2)	1.5 (0.1)	1.2	.150
Rx (cm)	13.7 (2.7)	12.6 (3.1)	12.7 (2.7)	1.4	-.129
Ry (cm)	12.0 (2.3)	11.6 (2.5)	11.3 (2.5)	0.6	-.108
Rt (s)	3.6 (0.6)	3.7 (0.6)	3.7 (0.9)	0.07	.022

*$p < 0.05$

Mean DX were shorter and XV was slower than in good and very good scores, which also significantly correlated with scores. Table 4 shows Archers total drawing time (TDT), full drawing time and decrease in body weight after the clicker falls values of poor (8), good (9) and very good (10) score comparison and correlation.

Table 4. Male archer's total drawing time (TDT), full drawing time (FDT) and amount of decrease in body weight after release (DBW)

Score	8 n=34	9 n=35	10 n=39	F	n=108 r
TDT (s)	5.6 (1.4)	5.0 (1.0)	4.8 (0.9)	5.0*	-.280*
FDT (s)	2.6 (1.1)	2.4 (0.6)	2.3 (0.6)	1.6	-.173
DBW (kg)	7.0 (1.3)	6.8 (1.2)	6.4 (1.2)	1.8	-.186

*$p < 0.05$

Archers' aiming sways as they enter the target until the release, body weight shifts on left and right leg after the release and the IEMG % values one second prior to and after the release are shown in Table 5. Significant differences between scores for each archer are given in Table 6.

Table 5. Archers aiming sways as they enter the target until the release, body mass shifts on left and right leg before and after the release, and the IEMG% values one second prior to and after the release

n=108		t
TDX(cm)	13.0 (2.8)	4.5*
TDY(cm)	11.6 (2.5)	
BML1(kg)	39.0 (2.5)	47.8*
BMR1(kg)	32.6 (2.2)	
BML2(kg)	17.8 (2.2)	4.1*
BMR2(kg)	17.5 (2.3)	
F^1 %	83.2 (8.1)	48.2*
F^2 %	33.3 (7.1)	
D^1 %	85.4 (7.9)	78.6*
D^2 %	30.6 (3.8)	
T^1 %	72.4 (10.0)	-.274
T^2 %	72.9 (12.2)	
E^1 %	82.5 (8.1)	15.8*
E^2 %	57.7 (12.25)	

BML (body mass left leg before release); BMR (body mass left leg before release) [1]
BML (body mass left leg after release); BMR (body mass left leg after release) [2]
TDX: Displacement on target, left to right; TDY: Displacement on target, up and down
%: MVC; *$p < 0.05$

Table 6. Overview of significance differences between scores for each archer.

Score	8	9	10	F	A	r
MCRT (ms)	159.8 (22.6)	146.0 (10.7)	140.4 (12.3)	2.9	1	-.455*
D^1 %	32.1 (3.8)	30.4 (3.4)	27.2 (2.5)	4.0*	1	-.519*
F^1 %	87.0 (4.7)	82.9 (3.6)	80.2 (3.9)	6.1*	2	.557*
T^1 %	73.2 (6.4)	69.7 (5.6)	64.2 (5.5)	4.7*	2	.507*
E^1 %	86.9 (7.4)	77.7 (6.7)	76.1 (7.8)	6.9*	2	.549*
E^1 %	70.3 (5.3)	82.8 (6.2)	77.8 (7.0)	5.8*	3	.167
F^1 %	88.9 (5.0)	85.4 (5.2)	82.1 (7.3)	2.6	4	.419*
DY (mm)	7.0 (0.9)	10.0 (0.9)	4.3 (1.7)	3.0*	2	.286
DX(mm)	19.3 (6.2)	13.9 (10.3)	12.4 (6.4)	2.2	4	.380*
TDT (s)	6.6 (1.3)	5.4 (1.1)	5.3 (0.7)	3.8*	2	.433*
FDT (s)	1.6 (0.1)	2.1 (0.3)	2.0 (0.2)	4.3*	3	.329*
FDT (s)	2.2 (0.4)	2.1 (0.3)	1.9 (0.2)	2.5	4	.397*
FDT(s)	2.2 (0.4)	2.6 (0.7)	3.1 (0.8)	3.2*	1	.484*
TDX (cm)	15.8 (2.7)	13.7 (4.8)	12.0 (2.2)	3.9*	4	.491*

MCRT: Mechanical clicker reaction time
%: MVC; A: Archer; *$p < 0.05$

4. Discussion

When the results are examined, they vary according to flexor muscle one second prior to clicker falls, and performance increases when the muscular activity of flexor and deltoid muscles decreases. Also, activity of deltoid muscle one second after the clicker falls has decreased when performance increased (see Table 2). These findings were supported by the results of the study of Hennessy and Parker [9]. Deltoid muscle activity illustrated that the releasing mainly occurs on hand by hand muscles [10]. But when we analyze the findings as an individual, 2nd archer's flexor, trapezius and extensor muscle activities a second prior to the clicker falls have decreased when performance increased. But in the 3rd archer extensor muscles of the releasing hand a second prior to clicker falls have become more active when the performance increased. 4th archer's flexor activities a second prior to clicker falls decrease, but performance increases (see Table 3). Ertan *et al.* [4] revealed that after the fall of the clicker, all archers and non-archers presented an active contraction of the M. Extensor digitorum and all archers showed a gradual relaxation of the M. Flexor digitorum superficialis.

It has also been found that 1st and 4th archer's performance increases when mechanical clicker reaction time (MCRT) decreases, and additionally for the 1st archer, as the deltoid muscle activities a second after the clicker falls decreases, performance increases (Table 6). Therefore, we hypothesized that MCRT decreases in better scores. In this study it was observed that the performance of archers as a group has increased as the right to left or left to right postural sway (DX) has decreased. The 3rd archer within trials exhibited more front-back postural sway (DY), and therefore displayed increase in performance. Likewise the 4th archer, exhibited less right-left postural sway (DX), therefore, her performance increased (Table 6). In the light of this observation we assumed that some archers sway more than the others while targeting or focusing on the correct score. The findings of the study of Squadrone *et al.* [13] are not in line with this study. Very few observations were made relating to the drawing time of archers. In this study, performance of the group of archers has negative correlation with the total drawing time (TDT) because as the time increased the performance decreased (Table 4).

It has also been observed that archers aiming sways move more towards right-left on the target for better shots. Carlsoo [14] stated that non-symmetrical load adopted during the draw is retained unchanged during aiming, but body balance is disturbed upon arrow release and load on both feet was reduced for a brief instant. Load was even shifted towards the right foot for a few tenths of a second [14]. This observation matches the findings of previous studies of Hennessy and Parker [10], who stated that as the bow string is released, the force from the bow tending to flex the bow arm joints is removed and the equilibrium established before release would be disturbed. This action may lead the force of the left leg to decrease [10].

5. Conclusion

In conclusion, it was established that archers develop a specific muscular strategy, aiming behavior and postural sway to better shoot an arrow. When we analyzed the archers both as a group and individual, there were many variables that affected performance simultaneously.

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