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Comparing the ability of controlling the bow hand during aiming phase between two elite and beginner female compound archers: A case study

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ABSTRACT

The main purpose of this study was to compare the ability of archers in two different levels of expertise in controlling the bow during aiming phase. To achieve best control on the bow, the critical point for archers is to use bones, not muscles. Magnitude of postural angles and also total moment in the bow wrist joint can be good indicators of wrist muscles activity. Two female archers in elite and beginner levels of skill had participated in this research. 3-D coordinate data of upper body marker set were collected at 200 Hz using motion analysis system. Hyperextension and ulnar deviation angles during aiming phase were obtained from kinematic analysis. Moreover, moments were calculated by implementing static equilibrium equations to the biomechanical model of archer's bow hand. Results revealed that muscles responsible for hyperextension and ulnar deviation are significantly more activated in the beginner archer. Having muscles highly contracted, makes the beginner archer tired much sooner. This will cause the archer's ability descend during competition. Therefore control ability of bow wrist can be an indicator of archer's skill level and applied as an important parameter in talent identification, training, skill level estimation and assessment of performance improvement in archers.

Keywords: Archery, skill, bow hand, control.

INTRODUCTION

Archery can be described as a comparatively static sport requiring strength and endurance of the upper body [1]. Skill in archery is defined as the ability to shoot an arrow to a given target in a certain time span with accuracy [2].So the sense of sight is an important factor in archery. Hashemi et al., (2012) believe that people who are affected from visual insufficiency have a slower development process in comparison to normal people. Their major problems are disorder of posture, muscle development and body balance insufficiency [3] which are, as mentioned below, vital parameters for an archer .According to large number of shots undertaken in one competition, the shooting movement of the archer is required to be well balance and highly reproducible". Nishizono et al., (1987) divided these phases into six: bow hold, drawing, full draw, aiming, release and follow-through [4]. Each of these phases represented a stable sequence of movements and was ideal for studying the motor control and skill acquired during this voluntary kinematic process. Additionally, skill in archery directly depends on interaction between the subject, the bow and the arrow during executing the shot [5], and both training and competition do demand a certain extent of long hours of concentration with some physical ability such as strength, endurance, and postural fine control [6].Totally any struggle through athletes physical abilities cause to prevention of an injury is a crucial step to reach to physical training worthwhile goals[7].

Bow hand placement is where the shot begins and ends. That is to say, the bow hand is the first body part to touch the bow handle and the last body part to be touching it as the arrow crosses the rest. Archer must get it correct at the first moment of touch and keep it there through the shot. Getting the bow hand in place and relaxed will ensure that no torque will be transferred to the handle during the remainder of the shot. Improving the bow hand placement will make a big difference in archer's score [8]. Therefore, it is very important for an archer to have a complete control on his/her bow hand during aiming phase. Regarding this fact, Roland et al.,(2011)present some technique to prevent control problem.[9] and Ganter et al., (2010) have recently compared different methods of measuring the movement of the bow in the aiming phase [10]. Also it is believed that to achieve best control on the bow, the critical point for archers is to use bones, not muscles. The archer must consider how to structure a shooting technique to maximize the use of bones and minimize the use of muscles, because bones don't get tired yet muscles most certainly fatigue. Consistency in archery shooting depends on adopting a posture in which forces between the archer and bow are correctly aligned. Muscles play an important role maintaining the correct posture and releasing the arrow. The utilization of bigger proximal muscles is thought to promote consistency due to the higher tolerance for fatigue than the smaller distal muscles [11].As each archer has different muscle activities influencing score and speed [12], many researches in biomechanics of archery have described the different coordination and muscular activation patterns in archers during the releasing phase. Most of these studies have used electromyography to describe the muscular activity during archery shooting [13, 14, 15 and 16]. Electromyogram (popularly known as the EMG) is the measure of the biological potentials associated with muscle activity. [17] But in current study, posture and moments of bow wrist joint was measured instead.

The main purpose of current study was to compare the ability of archers in different levels of expertise in controlling the bow during aiming. To maintain static equilibrium of the bow during aiming phase, muscle forces have to contrast with the moments of external forces applied to the bow hand. These wrist and forearm muscle forces exert moments on wrist joint. Therefore, magnitude of total moment in wrist joint can be an indicator of wrist muscles activity. Also, posture of hand and forearm, and anatomical angles of wrist joint can reveal which group of wrist muscles are contracted to make this posture.

MATERIALS AND METHODS

1.1. *Participants*

Pre-test measurements such as archers' weight and height were performed on a number of archers due to choose subjects with similar anthropometric conditions. Two female compound archers in elite and beginner levels of skill had participated in this research. The elite one was a national team archer of IRI and the beginner one was chosen from a city club.

Table 1: Participants

	Skill Level	Gender	Age (years)	Weight (kg)	Height (m)	Training Background
Subject #1	Elite	F	29	52	1.56	10 years
Subject #2	Beginner	F	24	55	1.55	5 months

1.2. *Testing procedure*

Each subject participated in a single test session. Measurements were made under laboratory conditions in Biomechanics Laboratory of Ergonomics Division in University of Social Welfare and Rehabilitation. The market set we used is shown in Fig1. Three reflective markets were placed on each archer's bow forearm joints including: first knuckle of the forth finger, ulnar styloid and olecranon. The hand limb was defined as a link connecting the first knuckle of the forth finger and ulnar styloid. We considered ulnar styloid and olecranon as wrist and elbow joints respectively. And so, the forearm limb was defined as a link connecting these two joints together. Additionally, a marker was also placed on the first knuckle of forth finger of drawing hand to make it possible to measure the exact draw length of the bow.

Fig 1. Marker set schematic

Both subject completed five trial shots to get acquainted with the measurement conditions. Then, subjects completed two successive shots at the experimental part of the study.

Fig 2. Tensile test of bows in Zwickmachine

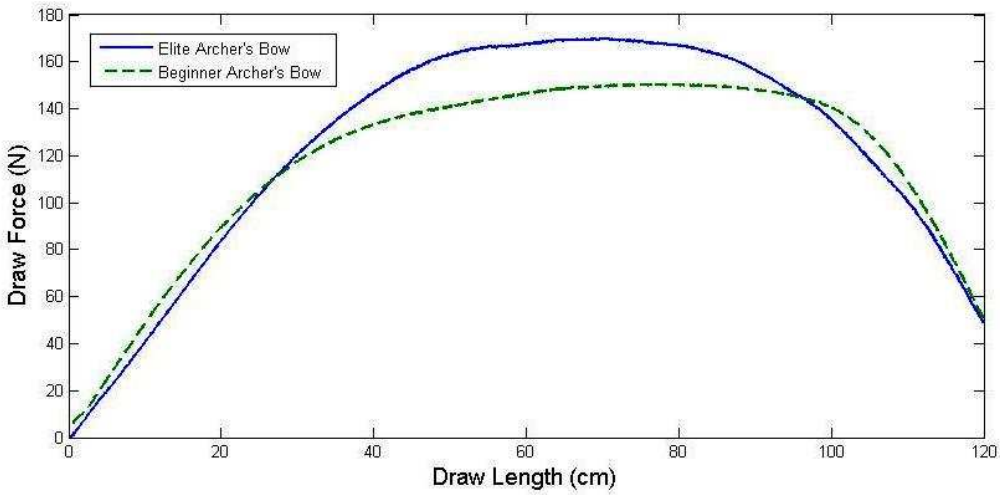

Fig 3. Draw-Force curves of participants' bows measured by Zwick machine

1.3. *Data collection*

3-D coordinate data of upper body marker set were collected at 200 Hz frame rate using a 6 camera VICON® motion analysis system during each shot executed by archers. Additionally, in another experiment in Mechanical Properties of Material Laboratory in Amirkabir University of Technology, both archers' bows were tensed in a Zwick machine and the curves of bow force(Newton) vs. draw length (centimeter) were obtained (see Fig2 and Fig3). Moreover, the draw length was obtained by subtracting the bows brace heights from spatial distance between markers on both hands fingers detected through motion analysis. Therefore, accurate magnitudes of the archers' bows forces at full draw position were measured using the curves provided by Zwick® tensile test. Also, the exact weights of bows were measured to import it in the calculations.

1.4. *Data processing*

Postural angles were excluded from kinematic analysis of motion capture data. Wrist anatomical angles containing *hyperextension* (θ_1) and *ulnar deviation* (θ_2) were obtained by projecting the bow hand and forearm postural angles on the main movement planes of the wrist:

θ_1: Bow wrist hyperextension angle; the angle between projection of bow hand and forearm on wrist the hyperextension plane (x-y)

θ_2: Bow wrist hyperextension angle; the angle between projection of bow hand and forearm on the wrist ulnar deviation plane (x-z)

Additionally, external forces including bow draw force, bow weight and hand weight plus acquired data from previous part of study, were implied in the archer's bow hand and forearm biomechanical model (Fig.4). Joint moment, $\vec{M}_{wrist}\ (M_x, M_y, M_z)$ was calculated by implementing static equilibrium equations to this model (Equ.1). Anthropometric parameters of this model such as length and mass of upper-extremity limbs were calculated based on the anthropometric tables provided by David Winter [14].As mentioned before, the bow was assumed as a two-force member connecting markers on lateral sides of proximal phalanges of fourth fingers in drawing and holding hands. In this model, M_x, M_y and M_z respectively account for supination/pronation, ulnar/radial deviation and flexion/ extension/ hyperextension movements in wrist joint.

Calculations were performed in MATLAB® and Microsoft Office Excel softwares.

Fig 4. Biomechanical model of archer

$$\sum M_{wrist} = 0;$$
$$\Rightarrow \vec{M}_{F_{bow}} + \vec{M}_{W_{bow}} + \vec{M}_{W_{hand}} + \vec{M}_{wrist} = 0 \quad \textbf{Equ1.}$$
$$\Rightarrow \vec{M}_{wrist} = -(\vec{M}_{F_{bow}} + \vec{M}_{W_{bow}} + \vec{M}_{W_{hand}}) = 0$$

Where:
$\vec{F}_{bow}$: Draw force of bow;
$\vec{W}_{bow}$: Weight of bow;
$\vec{W}_{hand}$: Weight of bow hand;
$\vec{M}_{wrist}$: Moment of wrist mainly produced by related muscles to opposite the external moments;
$\vec{M}_{F_{bow}}$: Moment of bow draw force exerted on the wrist;
$\vec{M}_{W_{bow}}$: Moment of bow weight exerted on the wrist;
$M_{W_{hand}}$: Moment of bow hand weight exerted on the wrist;
$\sum M_{wrist}$: Sum of all moments exerted on the bow wrist;
$\vec{M}_{F_{bow}} = \vec{r_1} \times \vec{F}_{bow}$;
$\vec{M}_{W_{bow}} = \vec{r_1} \times \vec{W}_{bow}$;
$\vec{M}_{W_{hand}} = \vec{r_2} \times \vec{W}_{hand}$;
$\vec{r_1} = (x_{finger} - x_{wrist})\vec{i} + (y_{finger} - y_{wrist})\vec{j} + (z_{finger} - z_{wrist})\vec{k}$and
$\vec{r_2} = (x_{hand\ center\ of\ mass} - x_{wrist})\vec{i} + (y_{hand\ center\ of\ mass} - y_{wrist})\vec{j} + (z_{hand\ center\ of\ mass} - z_{wrist})\vec{k}$;

RESULTS AND DISCUSSION

Regarding this fact that the moment drive from the multiplication of force and distance, and also since$\vec{W}_{hand}$, $\vec{W}_{bow}$ and $\vec{F}_{bow}$ at aiming phase are almost equal in both cases, so, the magnitude of $\vec{M}_{wrist}$will be mainly affected by archers' bow hand and forearm posture.

Line graphs of bow wrist joint moments obtained from the biomechanical model for both archers are shown in figures 5 to 7. As illustrated by curves, magnitude of moments produced in elite archer's wrist is significantly smaller than the ones produced in beginner archer's wrist. Another noteworthy difference can be observed in these curves is that the duration of aiming process is obviously shorter for the beginner archer (about less than half of the elite archer's). It seems like she couldn't tolerate this amount of moment and had to release the arrow much sooner in comparison to the elite archer.

Regarding attained anatomical angles marked in figure 8-11, beginner's hand is hyperextended from 31.697 to 36.866 degrees during aiming phase, while elite's hand is hyperextended from 23.190 to 24.544 degrees. This reveals that extensor carpi radialis longus, extensor carpiradialisbrevis, and extensor carpi ulnaris muscles are more activated in beginner archers. As well, beginner's hand is ulnar deviated from 6.979 to 13.764 degrees while elite's hand is ulnar deviated up to 3.518 degrees from full draw till release. It shows that flexor carpi ulnaris and extensor carpi ulnaris muscles are more activated in beginner archer. These anatomical angles completely confirm the results obtained from calculation of moments.

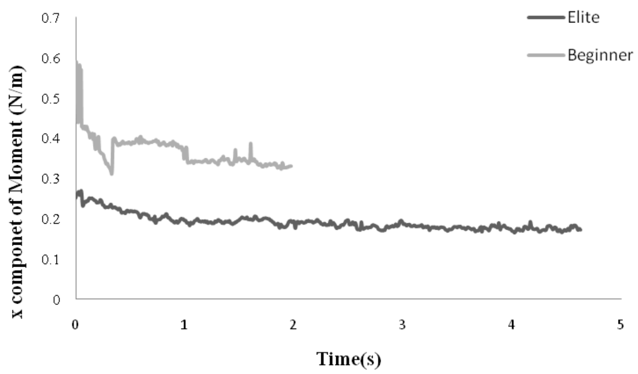

Fig 5. Comparing "x" component of bow wrist moment in elite and beginner archers

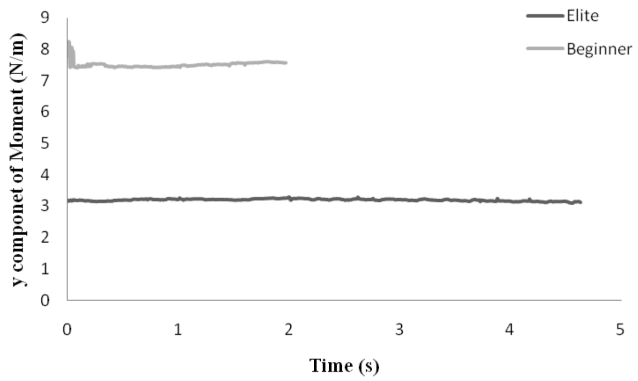

Fig 6. Comparing "y" component of bow wrist moment in elite and beginner archers

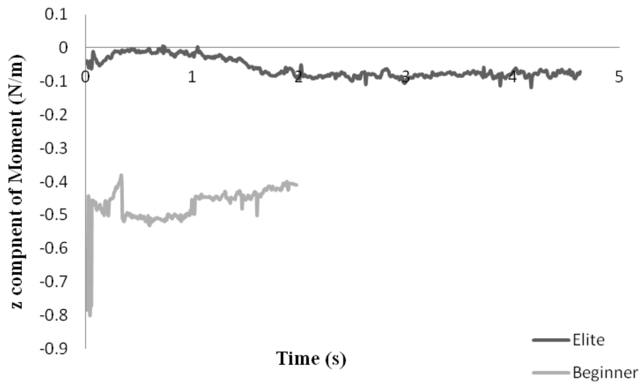

Fig 7. Comparing "z" component of bow wrist moment in elite and beginner archers

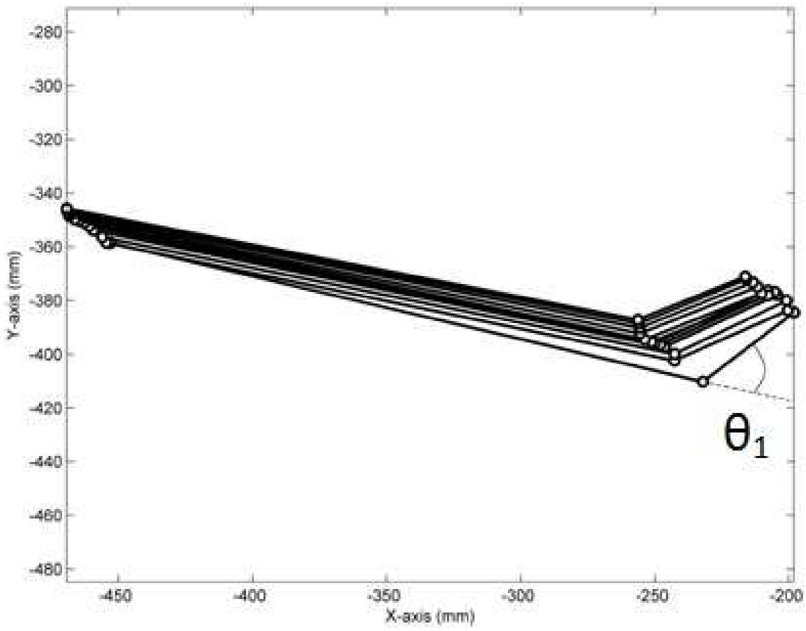

Fig 8. Projection of forearm and hand Stick figure on x-y plane – Angle: θ_1 in beginner archer

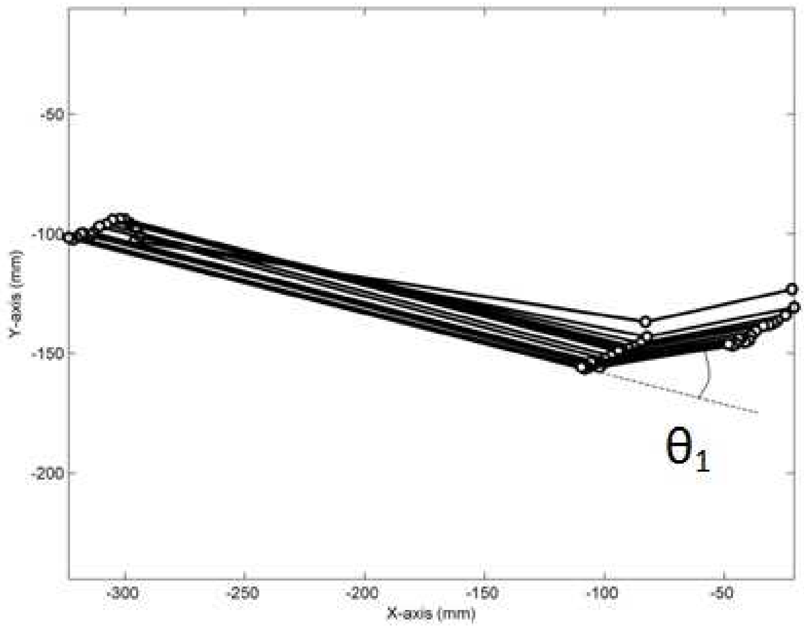

Fig 9. Projection of forearm and hand Stick figure on the flexion/extension/hyperextension plane – Angle: θ_1 in elite archer

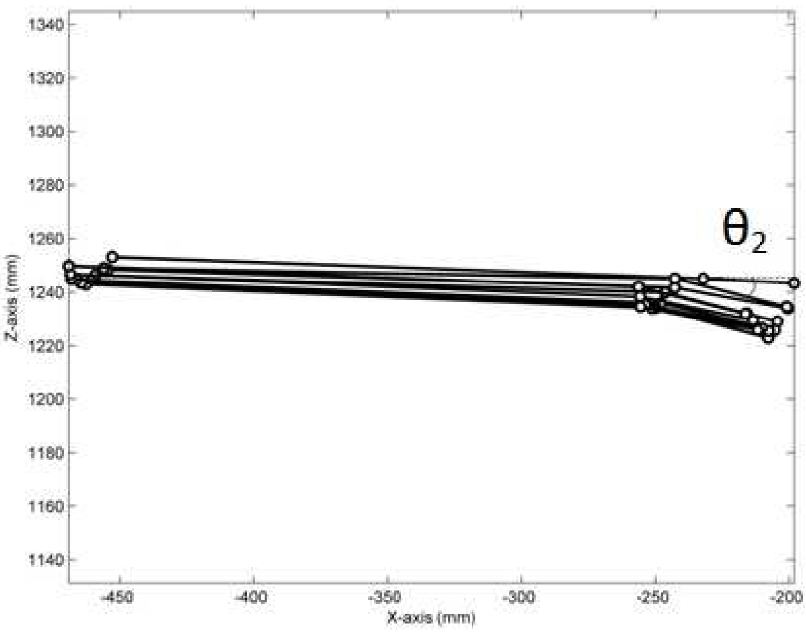

Fig 10. Projection of forearm and hand Stick figure on x-z plane – Angle: θ_2 in beginner archer

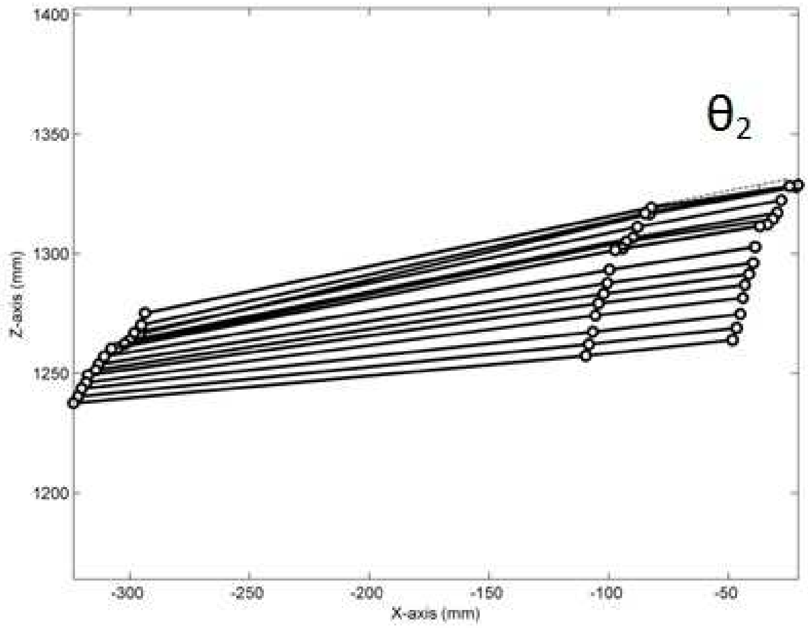

Fig 11. Projection of forearm and hand Stick figure on x-z plane – Angle: θ_2 in elite archer

CONCLUSION

According to motion analysis outcomes, posture of archer's arms (both drawing and holding arms) is the main factor affecting length of moment arm and therefore magnitude of exerted moment to the bow wrist. The results reveal that the beginner archer experiments more amount of moment in her bow wrist during aiming phase, in hence needs more activity in her wrist and forearm muscles to hold the bow in a fixed appropriate position. This means that wrist muscles should be more activated in the beginner's hand in comparison with the elite archer. Additionally, the elite archer has spent more time on aiming. It seems like the beginner archer has been obliged to release the arrow much sooner because of experimenting heavier load on her wrist.

As figures 5-8 show, beginner's hand is significantly more hyperextended and ulnar deviated in comparison with the elite's. Since bearing this load is not possible for more than few moments, the beginner archer has to release the arrow as soon as possible. In contrast, the elite archer may spend more time aiming and has a chance to perform the shooting process more accurately and hit a better score. So An archer's skill level directly affects his/her ability to control the bow during aiming phase.

Furthermore, because of large number of shots needed to be done during an archery competition, shooting procedure should be highly reproducible. Having muscles highly contracted, makes the beginner archer tired much sooner. This will cause the archer's ability descend during competition.

Altogether, owing to effective role of archery expertise on ability of controlling the bow through aiming, this ability can be an appropriate indicator of archer's skill level and applied as an important parameter in talent identification, training, skill level estimation and assessment of performance improvement in archers.

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