Introduction

Archery can be defined as a non-contact, static sport that requires its archers to possess muscular strength, upper body endurance and high levels of stability. These performance variables are required specifically at the trunk region, shoulder girdle, and for both arms to ensure shooting accuracy, and score of the shoots which eventually determine the winner (Ertan, 2009; Soylu, Ertan, & Korkusuz, 2006). Besides strength and endurance, postural stability is another crucial variable in determining the outcome of every shot. An archer's skill is evidenced in the ability to shoot the arrow to the specific target within a specific time. To achieve this, athletes need to minimize their movements in each step or phase to avoid unnecessary movements which can reduce stability, thus, minimizing the chances of hitting the centre target. An archer's movements must be as precise as possible, coping fast with postural instability (Kuo, Chi, Yu & Tsung, 2005; Ertan, 2009; Ertan, Kentel, Tumer, & Korkusuz, 2003; Kuo & Chi, 2005).

In precision aiming tasks, postural stability tends to be the most important variable that needs to be controlled in order to achieve the highest performance. Having a high level of postural stability when aiming increases the aiming stability of the archer. Aiming stability ensures uninterrupted flight trajectory to the target and this situation gives impact to the performance outcome (Kuo et al., 2005). Therefore, archers, regardless of their performance level, are affected by postural sway (Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996; Ball, Best & Wrigley, 2003; Mononen, Konttinen, Viitasalo, & Era, 2007).

The most important phase in determining the success of every shot in archery is the aiming and releasing phase, followed by the follow-through phase. Once the archer has begun to draw the bow and starts aiming at the target, he or she tends to maintain the posture of the arms and trunk, keeping it fixed to ensure that the arrow is properly aligned with the intended target. When postural movements have been minimized, the archer can easily focus on the target itself (Balasubramaniam, Riley, & Turvey, 2000). Stability of the shooting needs to be maintained at the highest level in order to obtain a good and small score deviation. One of the important subcomponents in maintaining shooting stability is aiming stability, which also appears to be the main factor that affects shooting performance. Aiming stability is defined as the locus pattern of aiming and it is noted that the expert archer's aiming locus is much smaller in contrast to beginner archers (Ertan et al., 2003; Ertan, 2009; Kuo & Chi, 2005).

Postural Sway and Aiming Stability

Posture can be defined as the geometric relationship between different body segments (Balasubramaniam & Wing, 2002). In other words, posture encompasses body joints angles. For example, the right arm wrist and elbow angles describe the posture of string arm for right handed archers. Body posture serves two functions. Firstly, it serves as a standing position point of reference wherein posture works as antigravity and plays a major role in keeping body balance. The balancing function is affected by preventing falls through maintaining the centre of gravity within an individual (Fisher, 2010). As such, in normal standing positions, the postural control system's main function is to integrate the antigravity and balance functions of the body. Secondly, body posture functions as a reference framework for movements. It provides the head, torso, hip, legs and other body segments a framework for moving towards any specific target or performing any movement (Fisher, 2010).

In order to achieve the highest point in archery, every shot must hit the centre or near the centre of the target. Archers need to control their movements at every phase to affect precise aims and release arrows at accurate sighting points. Accurate sighting points can be achieved by maintaining or maximizing aiming stability. To sustain aiming stability at the highest level, archers need to maximise postural stability whilst controlling every other aspect in their aiming prior to the shoot. Earlier research illustrated that by increasing aiming and equipment stability, the shooting scores are also increased correspondingly. Besides equipment stability, postural stability also plays a major role in determining performance. Archers or shooters who are able to control their postural stability have a more stable platform in aiming and this increases performance as compared to those who cannot control postural balance (Mononen et al., 2007).

Archer's expertise also plays a major role in determining whether they are able to cope with postural stability. Era et al. (1996) suggest expert athletes are able to rapidly stabilize postural stability compared to beginner and novice athletes. Moreover, these athletes are able to control postural stability right to the end. This appears to be acquired through training and competitive experiences, thus enabling them to manipulate their posture in order to achieve positive outcomes. The present study seeks to determine the possible causal relationship between postural sway and shooting performance.

Materials and Methods

Participants

Twenty-one (n = 21) skilled archers from Peninsular Malaysia participated voluntarily in this study. The skilled archers comprised of both genders and were aged between 13 to 25 years. They are considered skilled due to their qualification scores of 1150 upon 1440 full FITA score in either national or international rank competitions.

Instrumentation

To quantify postural sway value, Zephyr Bio-Harness devices (model PSM Research version 1.5, single transmitter and receiver) were used instead of force platform (reliability 0.841 - 0.941). The transmitter was set to transmit live data feed as opposed to hard drive recording. Subsequently, live data were transformed into graphs and figures in 10-second lengths per draw with 15 frames per second drawing feed. A laptop (model Toshiba Satellite L510, 3Gb ram capacity, 4.60Ghz processing capabilities) was used to compute all equations with software from Zephyr (version 2.3.0.5) that enabled comparison of multiple data and capturing real time data transmission. A digital video recorder (model Sony Handycam DCR-SR68E) was used for video recording purposes. Every participant's shooting was recorded for further analysis.

Procedures

A shooting area was constructed at the respective testing sites. The shooting area prepared included two target butts and target stands that were situated 30 meters from the shooting line for official target practice and official data collection. Multiple 10-meter targets were set up for warming up prior to target practice and the official data collection period.

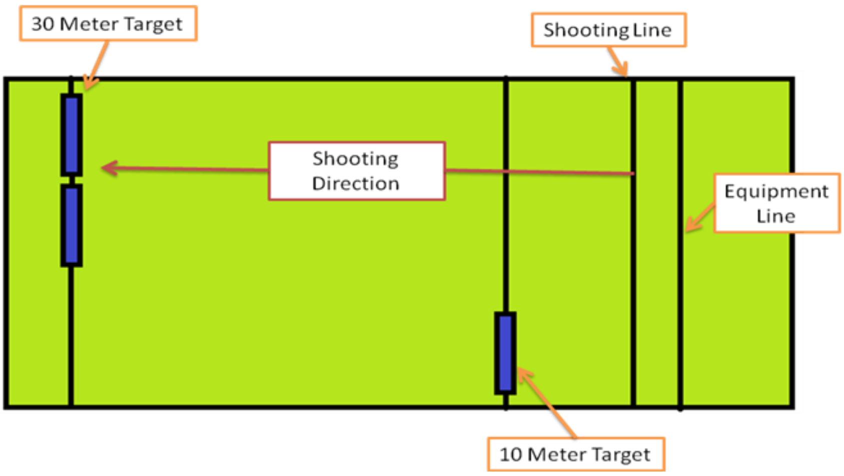

Figure 1: Shooting Area for Data Collection

Participants were briefed on the purpose of the study and the procedures involved. Letters of consent were signed a week before to waive any accidental occurrences during the test that are not related with the test protocols. The study was also approved by the UiTM research ethical committee (reference no: 600-RMI [5/16]). Prior to data collection, ample warming up time was given to the participants for short distance targets. This warming up session lasted 15 minutes. Participants were required to obey the shooting regulations which limit long end shooting in a four-minute time period. For this time limit, usually archers need to shoot a minimum of six arrows whereas for the warming up session, participants are allowed to practice as many shoots as possible within the time limit. Shooting speed usually correlates with the expertise level. Expert or skilled archers are usually able to shoot 10 to 12 arrows in the time limit provided. For a 15 minute-warming up session, three ends of shooting were able to be conducted. Warming up involved either rhythmic or fast shooting techniques at 10-meter targets without any target face. This was important to increase body temperature and promote blood flow to the limbs in order to reduce the possibility of injury and prevent muscle soreness.

After thorough familiarization with the test conditions, participants were given 12 arrows for official target practice. They were to shoot at the 30-meter target but no score and postural sway value were recorded. Twelve arrows were shot in two ends within a four-minute time period for each respective end. Participants paced their own shooting time according to their expertise level. Arrows that were shot after the time limit ended were considered as misses with zero (0) marks awarded.

Participants were asked to complete 12 official shots at the 30-meter target. Shooting cue was given by either the researcher or researcher assistant. The target face used was the official FITA 80 cm 30-meter target. This target face consists of five colours and 11-point rings that reflect the score ranging from one to ten with the center ring marked as “X”. This ring brings a score of ten and is considered as highly accurate compared to the actual outer ten rings.

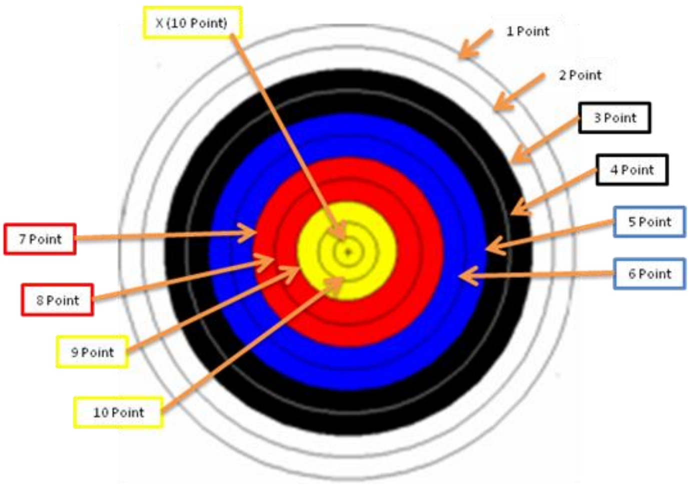

Figure 2: Target Face Diagram (Score Ring)

Participants were required to use their own bow and arrows for performance measurement purposes. Standardized prepared equipments by the researcher would inhibit participant’s own shooting style and shooting performance would be affected due to the difference in ergonomics and equipment characteristics. Archery equipment is personalized and archers need a familiarization period with new equipment settings to enable them to exercise good control whilst increasing their shooting technique consistency and persistency.

Each tested participants was equipped with a Zephyr Bio-Harness device, worn on the xyphoid process under the sternum. The device belt or garment is placed under the participant's shirt. The pilot study carried out showed that the device would not interfere with the bow string path and would therefore not affect the shooting characteristics. The participants were allowed to shoot with their preferred position but stance techniques were limited as they were required to use the straight stance. After putting on the Bio-Harness, the participants were asked to stand still with full equipment on the shooting line for 10 seconds to obtain a standing-upright posture value. Subsequently, the participants shot an arrow each time they were given a start cue until they finished shooting all the 12 arrows. Whenever the participants were in the stance phase, they were given a "start" command and the data was collected by starting the recording of the live data transmitted by the device. The transmitting of the real-time data was stopped after the participants finished the release and follow-through phases of the six arrows or end. All of the phases took about four to ten seconds depending on the athletes' expertise and level of performance. In this study, the subject's performance was individually observed and was digitally recorded.

Results

The participants' shooting performance was measured by their shooting scores from the twelve shots to the 30-meter target. The shooting scores ranged from zero to bulls eye (X, or ten points, the highest mark). Zero point was awarded if the participants missed the target face or the target, while the highest score was given to the participant that hits bulls eye. Figure 3 depicted the score distribution between skilled and unskilled participants.

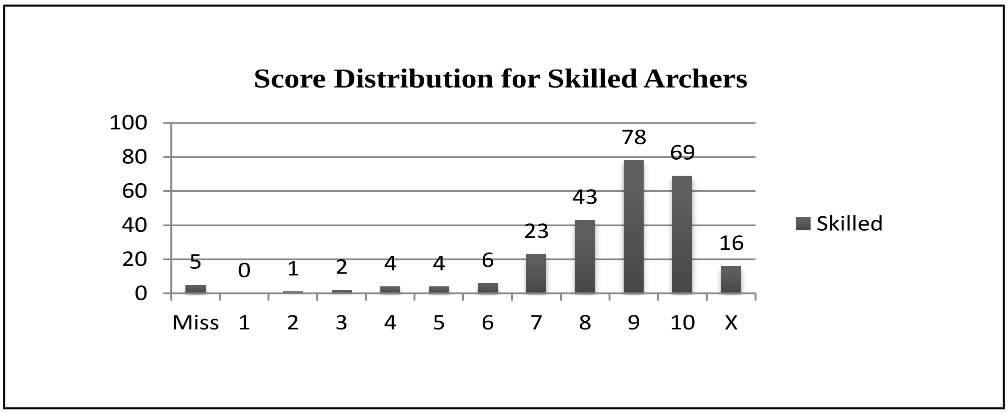

Figure 3: Score Distribution between Groups

The mean score for the skilled group was 8.58 points. For this group, the highest score was nine points (31.0%) followed by 10 points (27.4%) and eight points (17.1%). Two percent from a total of five arrows that missed the target constitutes the lowest score for this group. The lowest percentage score obtained by the skilled participant group was four and five (1.6%). Data obtained from the study illustrates variances in postural sway characteristics throughout shooting performance. As shown in Table 1, the least sway recorded was during the setup phase and the highest was during the aiming phase. During the setup phase, the sway was positive which indicates the occurrence of swaying to the anterior while for the aiming and release phase, negative reading was recorded indicating posterior sway.

Table 1: Postural Sway Value (Mean ± SD)

Phase	Postural Sway (^{0})
Phase 1 (Setup)	0.01 ± 7.532
Phase 2 (Aiming)	-1.56 ± 4.129
Phase 3 (Release)	-0.71 ± 4.675

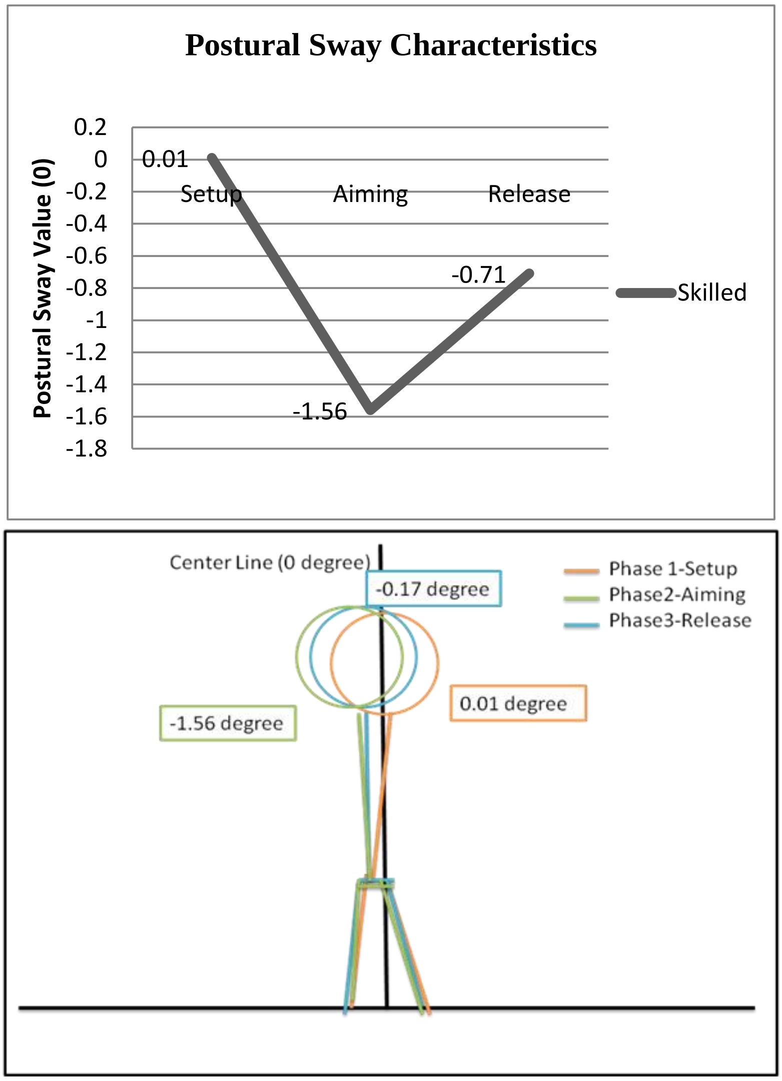

Figure 4: Diagram of Postural Sway Characteristics through Phases

Multiple regression analysis was applied to test the relationship between postural sway during shooting phases and shooting performance. Multiple regressions indicate that when body sway increased, shooting performance will decrease.

Table 2: Correlations between Variables with Shooting Score

Variables	Pearson Correlation	*p* value
Posture 1 (Setup)	-0.221*	0.001
Posture 2 (Aiming)	-0.021	0.367
Posture 3 (Release)	0.248*	0.001

** Significant level (p < 0.05)*

Table 2 shows the correlations and significant value of variables which contributed to shooting score performance of Malaysian skilled archers. The highest correlations are portrayed by postural sway characteristics during the release phase with r value of 0.248 and reached a statistically significant state at ($p < 0.001$). The second highest relationship was documented by postural sway characteristics during the setup phase (r = -0.221) with a significant value of ($p < 0.001$).

Table 3: Coefficients between Variables with Score for Skilled Group

Model	Standardized Coefficients Beta	*p* value
Posture 1 (Setup)	-0.174*	0.008
Posture 2 (Aiming)	-0.072	0.309
Posture 3 (Release)	0.262*	0.001

** Significant level (p < 0.05)*

According to Table 3, postural sway during the release phase contributes the most towards the model with standardized coefficients value of 0.262 ($p < 0.001$) with 23.8 percent partial correlation of overall model correlation. This variable makes the strongest unique contribution to explain the shooting performance of the skilled group compared to other variables, when the variance explained by all other variables in the model was controlled. The second highest contributor towards the model was postural sway during the setup phase with standardized coefficients of -0.174 ($p = 0.008$) with 16.7 percent partial correlation value. Regression analysis indicates that there is a significant result for the relationship between the model with shooting performance ($p < 0.001$). These data suggest that the model contributes towards shooting performance characteristics, thus indicating that there exists a significant relationship between postural sway across shooting phases with the performance of arrow shoots of the skilled Malaysian recurve archers.

Table 4: Model Summary for Skilled Group

Model	R Square	Adjusted R Square
Posture 1, Posture 2, Posture 3	0.105	0.094

Table 4 displays the R Squared and adjusted R square value. For this model, the R square value was 0.105 which expresses a percentage of 10.5 per cent. This means that this model explains the 10.5 per cent of the variance in skilled group shooting performance. A coefficient test was conducted afterwards in order to seek the variable that contributes the most towards the relationship between the model and shooting performance.

Discussion

The goal of this study was to determine whether postural sway affects shooting performance whilst examining the phase which directly affects shooting performance. Stuart and Atha's (1990) study which compared archers from different skilled levels and also examined those within the same level of performance revealed that the differences between skilled levels were smaller compared to differences between each respective shooting ends within each group. However, their research focused on movements of certain body parts such as the head, string arm elbow and bow handle. Prior studies also focused on the whole shooting process, while the current study examines the movements at three different phases of shooting.

The current study measures actual postural sway characteristics at outdoor shooting fields rather than in a controlled environment such as inside a test lab. This was to ensure the testing environment closely resembles the actual shooting with its surrounding ambiance, wind and weather conditions. Prior studies were all lab-based in an enclosed environment which did not resemble the actual environment. Additionally, the present study analysed multiple phases of the shooting process. Past studies mostly focused on one phase wherein overall data was compared between groups. In this study, overall performance was broken down into three phases; i.e. the setup, aiming and release phase. In so doing, the researcher is able to determine the phase that most impacts shooting performance rather than looking at it generally (Balasubramaniam, Riley, & Turvey, 2000; Era et al., 1996; Gautier, Thouvarecq, & Larue, 2008; Keast & Elliot, 1990; Miyamoto, 1994; Mononen et al., 2007; Stuart & Atha, 1990).

Vuillerme and Nougier (2004) noted that experts from different sports do not differ in terms of postural sway during unperturbed stance and during raised difficulties. This is because experts tend to increase their automatic ability of controlling postural sway, an ability harnessed throughout years of training and tournaments. Prior studies suggest that cognitive mechanisms are dependent on levels of expertise. Expert athletes are able to perform autonomously and with less effort as compared to non-experts. As such, more effort can be channelled to process other movements (Era et al., 1996; Gautier, Thouvarecq, & Larue, 2008; Vuillerme & Nougier, 2004).

The human body has an integrated system in order to maintain postural stability. The systems include visual, vestibular and somatosensory. This study showed that all the participants portrayed the same level of postural control. Crucially, it establishes a significant relationship between postural sway and shooting performance and proposes that postural sway during the release phase, rather than the setup and aiming phases, plays a major role in determining good shooting performance. According to practice-based automaticity theories, attentional demands are minimized when athletes are highly trained on postural tasks (Vuillerme & Nougier, 2004). Similarly, skilled archers are highly trained in order to achieve stable aiming and good shooting performance. Clearly, athletes who are highly tuned on activities are able to minimize their intentional demands on the performance itself because it has been automated by the body system. Since the movements of expert athletes are automated rather than controlled, expert athletes are able to focus on perfecting the techniques of shooting in order to obtain stable aiming and to get consistent shooting performance (Era et al., 1996; Gautier, Thouvarecq, & Larue, 2008; McKinney, 1996; Stuart & Atha, 1990; Vuillerme & Nougier, 2004; Wulf, 2008).

Data for Phase 1 and Phase 3 were less than 1.0 degree; it was also noted that minute sway contributes significantly to shooting performance. Positive data in Phase 1 indicated that skilled archers tend to sway to the anterior side during the setup phase. During this phase, archers are in the preparation phase to draw the bow and would have to adjust grip techniques, hooking and adjusting bow arm elbow height in order to get the best posture as possible for drawing. Negative data during Phase 2 and 3 reflect the archers’ sway towards the posterior part, which was to the backside. Phases 2 and 3 were was the aiming and release phases respectively wherein the archers tend to compensate the force of drawing via maintaining stability by swaying a bit to the back. During these phases, the muscles used are the back muscles, i.e. trapezuis, deltoids are used to pull the string instead of the biceps, triceps and the forearms muscles in order to maintain longer sustenance in the shooting (Ertan, 2009; Ertan et al., 2003; Ertan, Knicker, Soylu, & Heiko, 2011; Ertan, Soylu & Korkusuz, 2005; Kuo & Chi, 2005; Kuo et al., 2005; McKinney, 1996).

While the value of sway was small, it nevertheless impacts shooting performance. The current study data shows that during the setup and aiming phases, the correlation was negative indicating that by increasing postural sway value, shooting performance will subsequently decrease. However, during the release phase, the correlation was linear indicating that an increase in postural sway corresponds with increase in shooting performance. In this context, by increasing postural sway during release (-0.71), it means that the archers will start to sway back to the normal line. This stems from the fact that during the release phase, the sway was towards the posterior side. The data trend clearly shows that the archers were in the process to move to the center line as evidenced from the decreasing value of postural sway from the aiming phase to the release phase. This clearly illustrates that minimizing postural sway or by returning back to the center line or near to the center increases the consistency of the shooting performance of skilled recurve archers.

Conclusion

Postural sway, specifically at the release phase can produce inconsistency in shooting techniques thus disallowing archers to obtain the best score. Postural sway in whichever respective phases also plays a role in the overall shooting outcomes and must be controlled. Uncontrolled sway minimizes chances of winning by deteriorating aiming stability, thus resulting in lower shooting performance. Future studies on appropriate training programmes, or specialized apparels and apparatus for precision aiming task athletes should be conducted to minimize the effects caused by uncontrolled postural sways.

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