Journal of Quality Measurement and Analysis *JQMA* 20(3) 2024, 35-48
e-ISSN: 2600-8602 *http://www.ukm.my/jqma*
https://doi.org/10.17576/jqma.2003.2024.03

KINEMATIC COMPARISON FOR SINGLE SHOOTING AND FAST SHOOTING IN TRADITIONAL ARCHERY

(Perbandingan Kinematik Terhadap Panahan Tunggal dan Berturutan dalam Panahan Tradisional)

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ABSTRACT

The aim of this paper is to compare performance single shooting (SS) and fast shootings (FS) in Mameluke traditional archery. A group of 10 elites archer participated in the study with total of 100 shots perform. Joint angles of bow arm (BA) and draw arm (DA) are measured to compare the similarities and differences between the two shooting techniques. Angles data are aligned using Functional Data Analysis (FDA) and single averaged curve representating each shot is compared. Performance measurement such as Pearson correlation coefficient (r), Sprague and Geers metrics are used. Result shows that value of r falls in a range of 0.7 to 0.99, while Sprague and Geer metrics of magnitude and phase are between [0.03,0.14] and [0.03,0.16], respectively. The metrics values show a near-zero value and r is closed to one. Thus, the two shots are found to be relatively similar despite the difference biomechanically in completing 10 shots for each shooting technique.

Keywords: curve registration; kinematics; single shooting; fast shooting; mameluke technique

ABSTRAK

Tujuan kajian ini adalah untuk membandingkan prestasi panahan tunggal (PT) dan panahan berturutan (PB) dalam panahan tradisional Mamluk. Sekumpulan 10 orang pemanah elit mengambil bahagian dalam kajian dengan melakukan 100 panahan. Sudut bagi lengan busur (LB) dan lengan menarik (LM) digunakan untuk mengukur persamaan atau perbezaan antara kedua-dua teknik panahan. Data sudut dijajarkan menggunakan Analisis Data Fungsian (ADF) dan purata lengkung tunggal yang mewakili setiap panahan dibandingkan. Pengukuran prestasi seperti pekali korelasi Pearson (r), metrik Sprague dan Geers digunakan. Keputusan kajian menunjukkan bahawa nilai r berada dalam julat 0.7 hingga 0.99, manakala metrik magnitud dan fasa bagi Sprague dan Geer masing-masing diberikan antara [0.03, 0.14] dan [0.03, 0.16]. Nilai metrik yang dihasilkan adalah menghampiri angka sifar dan r pula menghampiri kepada angka satu. Oleh itu, kedua-dua panahan didapati serupa walaupun berbeza secara biomekanik dalam menyelesaikan 10 panahan untuk setiap teknik yang dilakukan.

Kata kunci: pendaftaran lengkung; kinematik; panahan tunggal; panahan berturutan; teknik mamluk

1. Introduction

Archery is an endurance sports that emphasizes upper extremity strength for executing the actions of drawing the string and pushing the bow during shooting (Ariffin *et al.* 2020; Dhawale *et al.* 2018; Simsek *et al.* 2013b). There are three distinct categories in archery, which are static, dynamic, and horseback archery. In archery activities, two arms are involved: draw arm (DA) and bow arm (BA) (Dorshorst *et al.* 2022). The bow arm is responsible for holding the bow, while the draw arm has to deal with drawing the bowstring.

The sport of archery has had significant growth and advancements in terms of equipment, techniques, and technology, resulting in the emergence of modern archery (Ariffin & Rambely 2016). Nevertheless, traditional archery remains pertinent in today's society because of its simplistic aesthetics and cost-effectiveness in comparison to modern alternative (Bianchi 2023). In modern archery, a singular standardized technique also called as single shooting (SS) is employed (Chiam *et al.* 2023). In contrast to traditional archery, archers have a freedom to employ techniques that best suited an individual preferences (Latham & Paterson 1970). There are six distinct events involved in both shootings, specifically stance (S), nock arrow (NA), pre-draw (PD), full draw (FD), release (R), and follow through (FT) (Lau *et al.* 2023).

Traditional archers employed the FS technique to shoot a specific number of arrows within a specific timeframe. This shooting technique is often used by archers in several categories of traditional archery, such as horseback, dynamic, and 3-D archery (Simsek *et al.* 2013a). In a traditional archery tournament, there are several categories listed, one of which is the FS category. The difference between FS and SS was readily apparent, archers must complete their shot within a specific timeframe. Traditional archery consists of multiple approaches, one of which refers to the prominent Mameluke technique. This technique encompasses two distinct approaches, namely Khatrah and Mafruk (torsion). The Khatrah technique incorporates the ulnar deviation of the wrist on the bow arm, followed by forcefully extending the hand by punching forward movement, while simultaneously rotating the bow perpendicular to the target (Ariffin *et al.* 2018; 2020). Using the Mafruk technique, the thumb on the draw arm will lock the arrow so that it remains fixed from its position.

There exists a limited number of scholarly articles that analyze archery activity from a biomechanical perspective (Horsak & Heller 2011; Kian *et al.* 2013; Liao *et al.* 2022; Serrien *et al.* 2018). A study presented by Horsak and Heller (2011) focused on the movement of fingers and hand during a release phase of the arrow of professional archer. However, the research involved only one subject, and the selected subject had a history of distal interphalangeal joint injuries, which had little effect on the study's findings. In their investigation. They found that pulling the bowstring towards the arm had no effect on the performance of the arrow.

Kian *et al.* (2013) conducted another study comparing the bow arm control of elite and novice female compound archers during the targeting phase. The moment values resulting from the novice archer's activities were found to be larger than those of the elite archer. These high moment values cause fatigue and discomfort in the arm muscles, in addition to the shorter time it takes novices to release arrow in comparison to elite archer. It is considered reasonable for an elite archer to take a longer time to aim in order to assure accuracy and achieve the highest level of success in archery. However, there is no indication of the accomplishments of the highly skilled subjects used in this study, aside from the fact that only one subject per category was recruited.

The Pearson correlation coefficient and the Sprague and Geers criterion may be used to assess the similarity between two sets of data. Biomechanical research have widely use this method to measure prediction by comparing their result (Marra *et al.* 2015; Peng *et al.* 2018; Purevsuren *et al.* 2016; Vanheule *et al.* 2017). The criterion matrices then underwent evaluation to determine the differences between the items being compared.

Currently, there have been no studies conducted on concerns of fast shooting or comparing two different shooting methods in traditional archery. Therefore, this study utilizes the static Mameluke technique in archery where the archer stands facing the target butt, with a specific emphasis on two shooting methods: fast shooting (FS) and single shooting (SS) specifically on draw and bow arm in term of joint angles that aims to compare performance of both shooting techniques throughout the shooting events.

2. Material and Method

2.1. *Subject preparation*

A total of 10 healthy elite traditional archers were involved in this study. The individual's height, weight, and bow poundage were reported as $168.9(\pm 3.65)$cm, $79.3(\pm 11.71)$kg and $41.5(\pm 6.59)$lbs, respectively. Each subject has competed in at least a tournament at the national level. All participants in this study completed informed consent before partaking in the experimental activities. This study was approved by UKM ethics committee (UKM PPI/111/8/JEP-2016-559).

2.2. *Task and measurement*

This study focused on collection of kinematic data specifically on angles of shoulder, elbow and wrist joint for both arms. In the SS task, each subject was allotted a 30-second rest period before commencing another shooting session. Conversely, in the FS task, subjects were directed to complete 10 cycles of shoots before being granted a 3-minute rest period. It is necessary for all participants to engage in a warm-up session lasting approximately 5 to 10 minutes. After a rest period, subjects resume with another set of shooting sessions. Ultimately, only the best five trials from each shooting event were chosen for analysis. During the experimental procedure, each participant was equipped with a set of 39 reflector markers, as depicted in Figure 1 (Vicon 2006). Additionally, the traditional archery cycle consists of six particular event which are stance (S), nock arrow (NA), pre-draw (PD), full draw (FD), release (R), and follow through (FT) where these events are shown in Figure 2. In total, there were 100 shots (50 SS and 50 FS) recorded in the range of six meter indoor target with a standard FITA (World Archery 2024) dimension of target butt and target face.

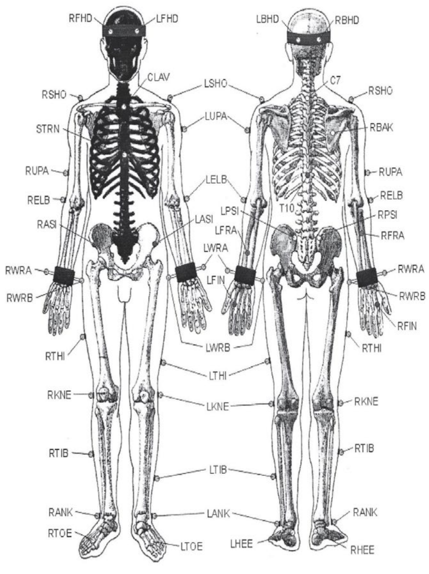


Figure 1: Reflector marker position

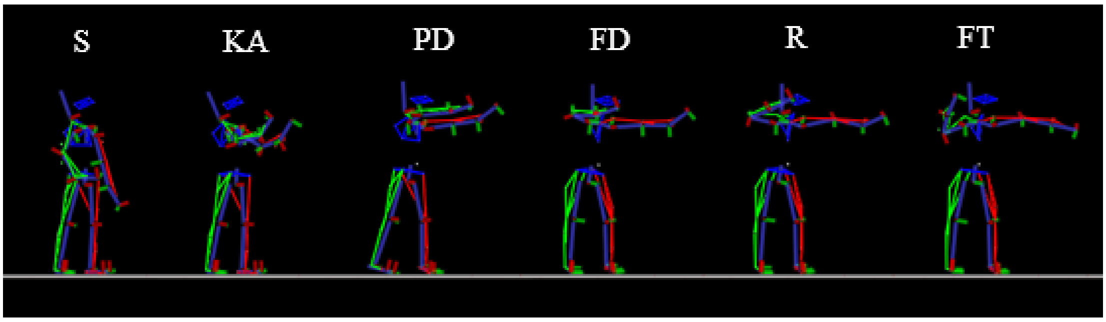


Figure 2 : Complete cycle of traditional archery

2.3. *Data acquisition*

2.3.1. *Equipment*

A Vicon Nexus version 1.4.2 was used to capture shooting activities. The subject is recorded at a sampling rate of 100 Hz using the Vicon MX Ultranet HD system, which comprises of five high speed infrared cameras (MX T40-S) that are permanently mounted. These cameras are equipped with the T40s lens.

2.3.2 *Procedures*

After all participated subjects completed the experiment, a digitization procedure was done in order to acquire the kinematic data from marker trajectories process. Figure 3 depicted a flow chart outlining the sequential processes employed to carry out the motion analysis experiment.

The kinematic data were analyzed as a discrete data either SS or FS. Each trial has a distinct time period, which must be time normalized before functional data analysis (FDA) procedures can be initiated. There are few FDA procedures involved such that normalization, continuous data registration, and curve registration. Finally, each trial shooting data (SS and FS) represented by a single average curve when kinematics data are further analyzed.

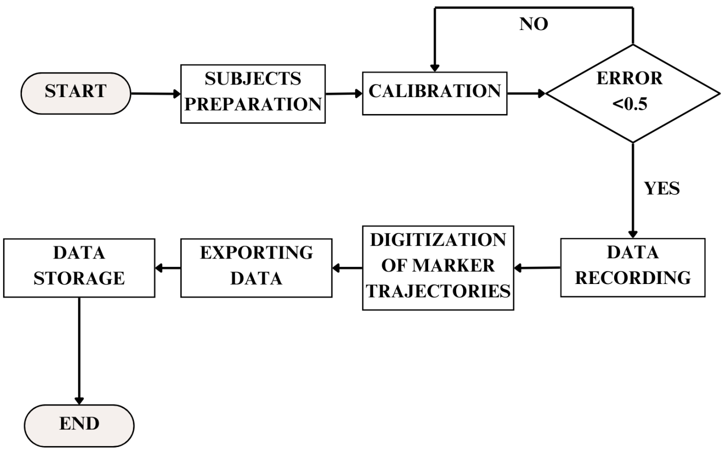


Figure 3: Motion analysis experiment procedures

2.4. *Filtering*

The FDA is often regarded as a highly effective approach for mitigating signal noise. Prior to proceeding with the FDA package in R, it is necessary to do a time normalization (100 data points) step using spline interpolation method in order to ensure that the data has the same length with respect to time. The time normalization formulation is given as follows;

$$Y = A + \frac{(Y_{ij} - A)(B - A)}{\max(B) - \min(B)} \tag{1}$$

where, A represents the smallest range value after normalization and B represents the largest range value after normalization, Y and Y_{ij} represent the newly normalized time and the original time value, respectively. Before curve registration is considered, all trials were collated according to the shooting activities (SS and FS). The utilization of the spline series is appropriate for non-periodic data, as it serves as a smoothing function to substitute the Fourier extension series (Ramsay *et al.* 2009) described as;

$$x(t) = \sum_{k=1}^{K} C_k \phi_k(t) = C'\phi(t) \tag{2}$$

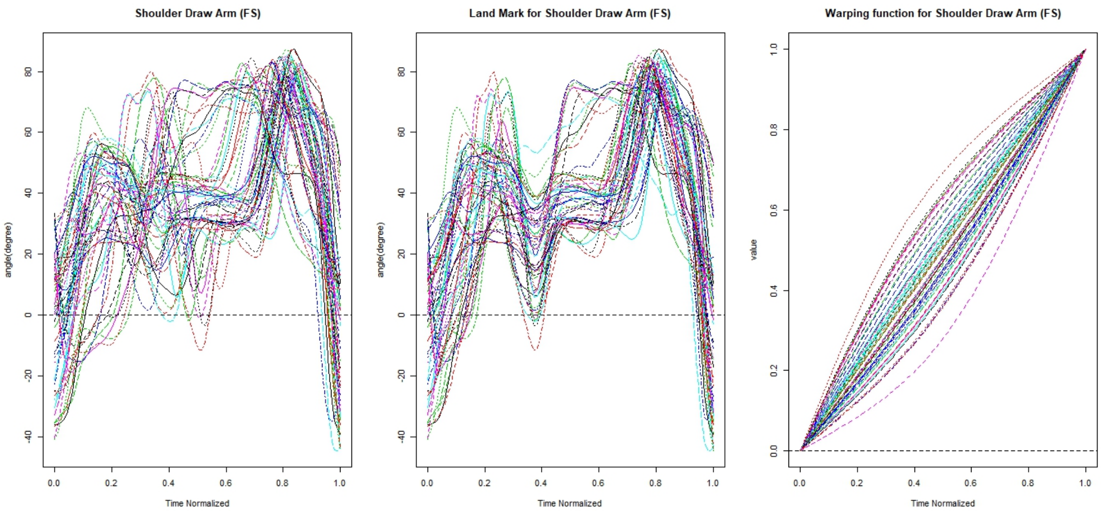
with C_k is an expansion coefficient and $\phi_k(t)$ is B-spline expansion function. The spline function is a piecewise polynomial, so the observation interval is divided into sub-interval called the break point (Ramsay *et al.* 2009). The Spline function is more flexible compared to the Fourier series in term of handling a functional data. After careful consideration of the parameters, the smoothing parameter $\lambda = 1 \times 10^{-06}$ and quintic spline (B-spline) basis have been finalized. These parameter then were used for all trials for the curve registration in FDA.

2.5. *Functional Data Analysis (FDA)*

After completing the selection process for the smoothing parameter, curved registration operation is executed. The curve registration approach has the ability to correct irregular curves by specifically addressing variations in amplitude, phase, and time that arise from differences observed in each individual trial. The curved shape is monitored in order to determine appropriate amount of locators that can be set. In order to facilitate the temporal alignment of phase and amplitude during the alignment process, it becomes necessary to estimate the time warping function within a certain temporal interval of followed by the constrains and Amplitude registration functions against time are as follows;

$$x^*(t) = x\left[h^{-1}(t)\right] \tag{3}$$

with uniform shifted function $h(t) = t + \delta$. While alignment function $h^{-1}(t)$ satisfied the equation $h^{-1}\left[h(t)\right] = t$ to ensure that the alignment process is executed with utmost effectiveness for all the kinematics trials data (Ramsay *et al.* 2009). Figure 4 showed all 50 smoothed time normalized angle data of shoulder draw arm of fast shooting archery at varies trial amplitudes (a), align trial amplitudes (b) and time-warping function (c).

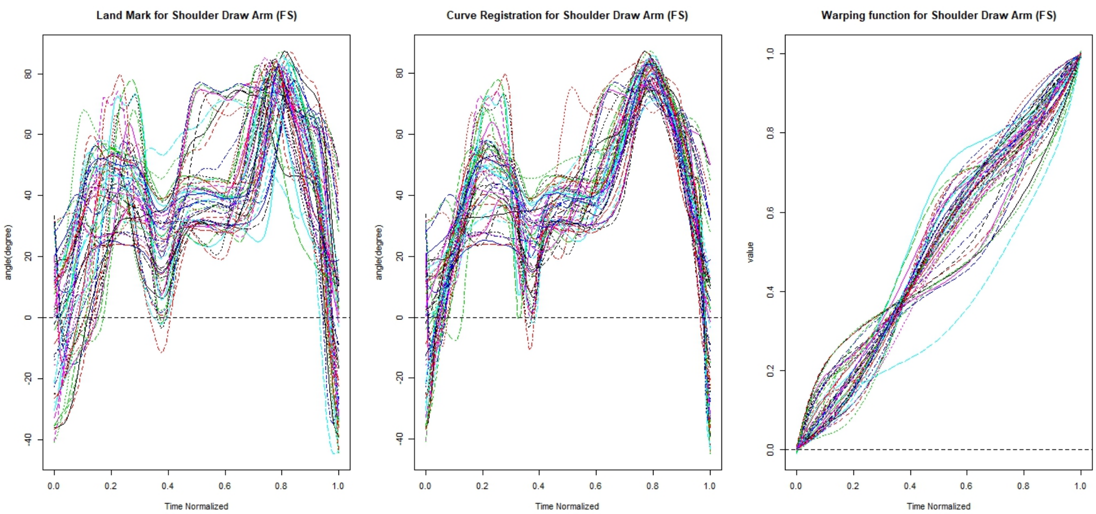


(a) (b) (c)

Figure 4: Sample of 50 angle data. (a) unregistered curve (b) landmark registration (c) time-warping function

Initially, the collective representation of all trials exhibited an observed variability in terms of amplitude. Upon applying the landmark locator to the designated peak of the curve, it was observed that all amplitudes exhibited a decrease in phase variability, as depicted in Figure 5. Both unregistered (varying trials amplitude) and landmark registration were plotted side-by-side so that differences could be identified.

Next continuous registration was done to fit and shape the data according to number of locator setting. Through the estimation of time-warping functions, phase variation in joint angle curves was eliminated. The use of landmark registration methods was used to improve the alignment of curves.. This technique gave the best solution to the curve so that phase variability in term of amplitude can be reduced (Zin *et al.* 2020).



(a) (b) (c)

Figure 5: Sample for curve registration data. (a) landmark registration (b) continuous registration (c) time-warping function

2.6. *FS-SS performance*

To perform a comparison of both archery activities of FS and SS, the Pearson's correlation coefficient (r) and the Sprague and Geers metrics of magnitude (M), phase (P) and cumulative (C) errors were utilized. This evaluation is capable of determining similarity between two data sets and providing insights about comparable data sets based on the magnitude and phase errors generated. In a context of *MPC* metrics, it is expected that the phase component (P) exhibited insensitivity against variations in amplitude, while demonstrating sensitivity towards disparities in phases or temporal aspects. Similarly, magnitude component (M) exhibited sensitivity towards variations in magnitude, while displaying relatively low sensitivity towards variations in phase (Kim *et al.* 2018; Mongiardini *et al.* 2009).

According to Purevsuren *et al.* (2016) a zero value for *MPC* metrices signifies that the anticipated and measured data curves were indistinguishable, but an absolute value of the total error (C) less or around 0.2 would be deemed acceptable as the difference. However, as stated by Mongiardini *et al.* (2010) the magnitude and phase component are considered acceptable when they are below one. This suggests that the comparison could be considered legitimate. The Sprague and Geers derivation are given as;

$$M = \frac{\sqrt{\sum c_i^2}}{\sqrt{\sum m_i^2}} - 1, \tag{4}$$

$$P = \frac{1}{\pi}\cos^{-1}\frac{\sum c_i m_i}{\sqrt{\sum c_i^2 \sum m_i^2}}, \tag{5}$$

$$C = \sqrt{M^2 + P^2}, \tag{6}$$

where c_i denoted the FS data set, m_i represented the SS data set, both of which indicated an instance in time frame of respective archery activity.

3. Result and Discussion

This section provided an elaboration on the results obtained from a group of 10 elite subjects. The flexion-extention kinematics data of shoulder, elbow, and wrist joints during archery activities, specifically for both single shooting (SS) and fast shooting (FS) were discussed. The angles of all joints were analyzed in accordance with six specific events, namely stance (S), nock arrow (NA), pre-draw (PD), full draw (FD), release (R), and follow through (FT) as shown in Figure 6.

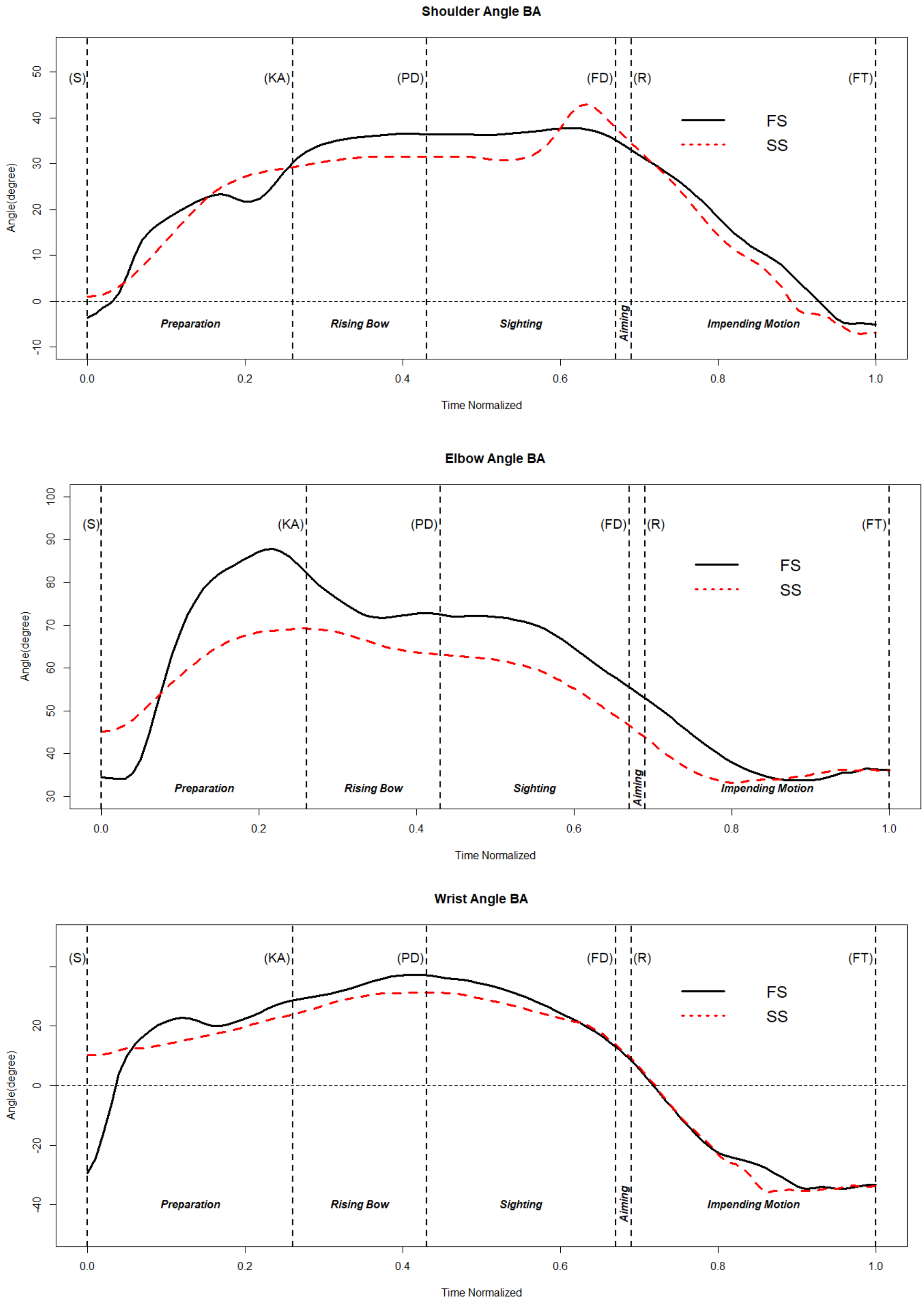


Figure 6: Joint angles for shoulder, elbow and wrist produced by bow arm (BA)

In the realm of archery, it has been observed that the FS archery activity consistently demonstrated a greater degree of angle when compared to the SS archery activity. Upon conducting a comparison between the angles generated by the FS and SS at the shoulder joint, it was observed that the approach employed exhibits a similar pattern. This may be demonstrated by the utilization of MPC metrics computed in Table 1. The Pearson correlation coefficient revealed a strong relationship between FS and SS for all joints, with coefficients of 0.97, 0.95, and 0.95 for the shoulder, elbow, and wrist joints, respectively. Table 1 presented the measurement metrics for the magnitude and phase metrics, which ranges from $0.06 \leq M \leq 0.14$ and $0.03 \leq P \leq 0.1$, respectively. This range indicated that magnitude and phase metric were nearing a value of zero for all angle joints. In addition, the cumulative metric values for the shoulder, elbow, and wrist joints were below 0.2, particularly 0.07, 0.15, and 0.14, respectively. The presence of three joints in both FS and the SS of archery style of shooting signified a resemblance in their joint angles characteristics.

Table 1: Pearson's correlation coefficient and MPC evaluation matrices for BA joints angle

BA Joints	Archery Activity	*r*	*M*	*P*	*C*
Shoulder	FS SS	0.97	0.06	0.05	0.07
Elbow	FS SS	0.95	0.14	0.03	0.15
Wrist	FS SS	0.95	0.1	0.1	0.14

Figure 7 depicted angle for shoulder, elbow, and wrist joints for DA. The FS and SS curves were graphed together to facilitate the scrutiny of their differences. Based on Figure 6, it could be shown that shoulder joint exhibited a consistent technique in both FS and SS. However, discrepancies have been seen in the early stage of the preparation phase of archery for the FS, particularly in the elbow and wrist joints. These inconsistencies arise due to the transition of the archery movement.

To measure the similarity of FS and SS in terms of their respective joint, the Pearson's correlation coefficient (*r*) and Sprague and Geers metrics were utilized for evaluation. Table 2 displayed the measurements of the angle of the shoulder, elbow, and wrist joints in relation to the activity of archery in the FS and SS. The shoulder joint had the highest correlation value between FS and SS, with a recorded value of 0.99. The wrist joint followed with a correlation value of 0.85, while the elbow joint had a correlation value of 0.7. The observed phenomenon can be attributed to the influence of the archery movement on the initial positioning of the elbow and wrist joints in the context of FS during the transition of archery cycle.

The magnitude and phase metrics indicated measurement in range of $0.03 \leq M \leq 0.07$ and $0.03 \leq P \leq 0.16$, respectively. The magnitude error for elbow joint produced the smallest amount of measurement compared to shoulder and wrist joints. In terms of phase error, the shoulder joint has the lowest value, followed by the elbow and wrist joints. Nevertheless, all of the measurements remain within acceptable limits since none of the value surpasses 0.2 (Purevsuren *et al.* 2016). Another metric measurement that may be evaluated is the cumulative metric for all three joints, namely the shoulder, elbow, and wrist joints, which were 0.06, 0.06, and 0.17, respectively. Although the shoulder and wrist joints yielded distinct values for Pearson's correlation coefficient, the cumulative measurements for both joints ultimately result in the same quantity.

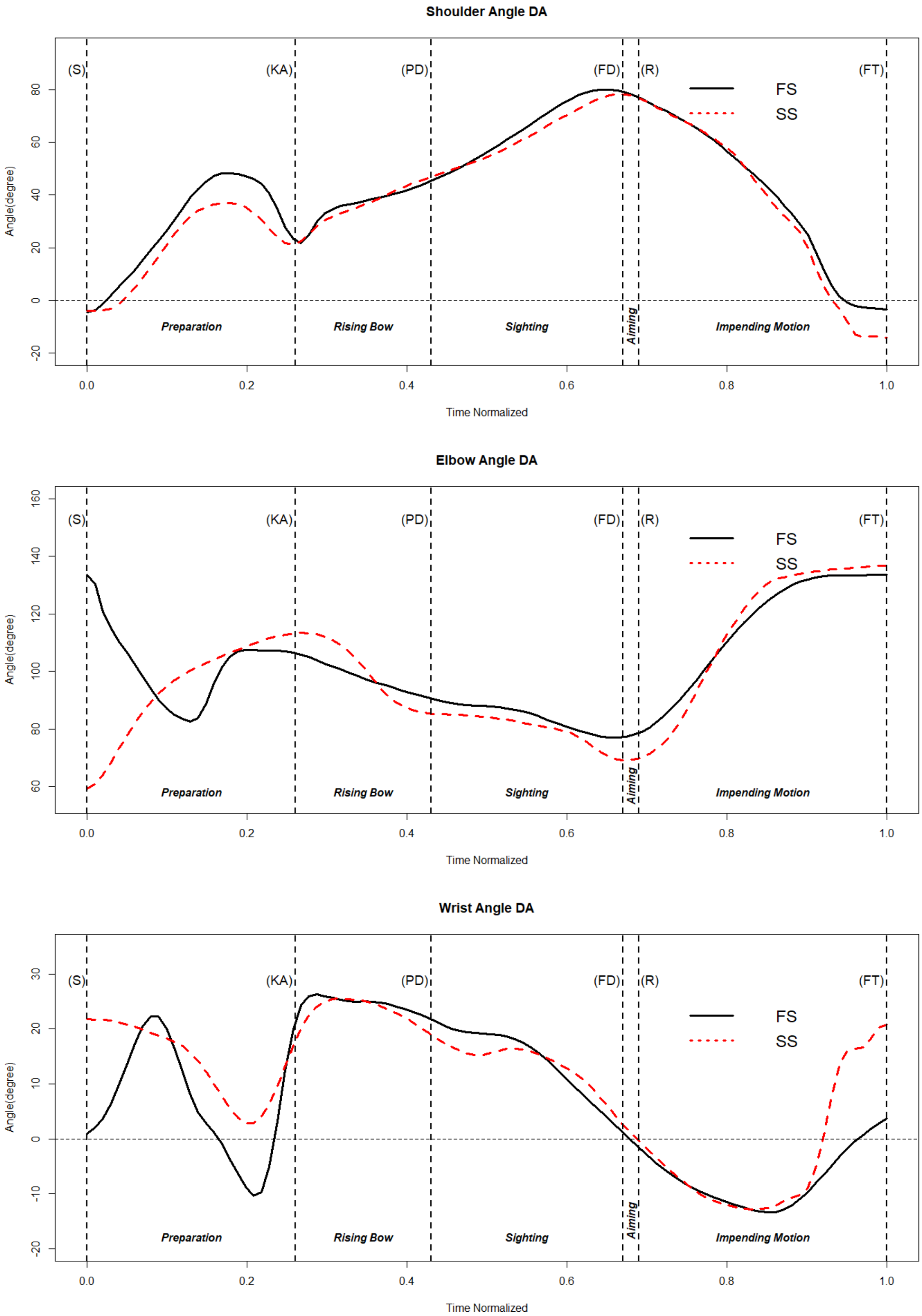


Figure 7: Joint angles for shoulder, elbow and wrist produced by draw arm (DA)

Table 2: Pearson's correlation coefficient and MPC evaluation matrices for DA joints angle

DA Joints	Archery Activity	r	M	P	C
Shoulder	FS SS	0.99	0.05	0.03	0.06
Elbow	FS SS	0.7	0.03	0.05	0.06
Wrist	FS SS	0.85	0.07	0.16	0.17

4. Conclusion

The present study investigated the similarity of average curve registration for FS and SS, focusing primarily on kinematic data pertaining to joint angle such as the shoulder, elbow, and wrist joints in relation to both BA and DA. Initially, a total of 100 trials were taken into consideration for both the FS and SS individually. However, for this study, a single curve of mean curve registration representing an average of each shooting was taken into consideration.

The result of the comparison demonstrated the efficacy of each metric in evaluating the extent of comparability across the FS and SS activities. In addition, potential acceptance criteria were proposed for each assessed measure based on the closed value derived from the analysis. Therefore, the comparison between FS and SS was found to be similar based on the r value, Sprague and Geers metrics.

Acknowledgments

The authors fully acknowledged Ministry of Higher Education (MOHE), Universiti Kebangsaan Malaysia (UKM), Universiti Teknologi MARA (UiTM) and Universiti Pertananan Nasional Malaysia (UPNM) for the approved fund (UPNM/2024/GPJP/SSK/1) which makes this important research viable and effective.

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Appendix

Subject preparation for this study was depicted in the figure below.

Figure 7 : Vicon Nexus system calibration front view

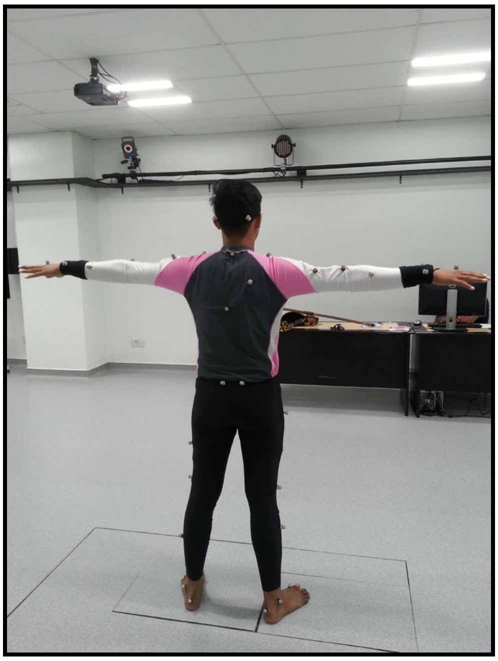

Figure 8 : Vicon Nexus system calibration back view

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Received: 11 June 2024
Accepted: 12 July 2024

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