ZHANG, Baifa and LIN, Zhi-Cheng. Comparative Analysis of Shooting Consistency Among Archers of Different Skill Levels. Quality in Sport. 2024;36:56935. eISSN 2450-3118.
https://dx.doi.org/10.12775/QS.2024.36.56935
https://apcz.umk.pl/QS/article/view/56935

The journal has been 20 points in the Ministry of Higher Education and Science of Poland parametric evaluation. Annex to the announcement of the Minister of Higher Education and Science of 05.01.2024. No. 32553.
Has a Journal's Unique Identifier: 201398. Scientific disciplines assigned: Economics and finance (Field of social sciences); Management and Quality Sciences (Field of social sciences).
Punkty Ministerialne z 2019 - aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 r. Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398.
Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).

The authors declare that there is no conflict of interests regarding the publication of this paper.
Received: 20.11.2024. Revised: 19.12.2024. Accepted: 19.12.2024. Published: 20.12.2024.

Comparative Analysis of Shooting Consistency Among Archers of Different Skill Levels

Bai-Fa Zhang[1]*, Zhi-Cheng Lin[1]

[1] School of Sports, Southwest University, Chongqing 400715, China
https://orcid.org/0000-0002-6746-0066

Abstract
Purpose: This study aimed to investigate the biomechanical and electromyographic factors underlying shooting consistency among archers of different skill levels, providing insights into performance optimization and training strategies. **Methods:** The study analyzed 28 left-handed archers, including elite, mid-level, and novice athletes. Using an eight-camera infrared motion capture system and a wireless surface EMG system, kinematic and muscle activity data were collected for key upper limb muscles during two action phases: drawing and aiming. Coefficients of variation (CV) were calculated for both kinematic and EMG parameters, and statistical analysis was conducted to compare the groups. **Results:** Elite and mid-level archers exhibited significantly lower CVs in key kinematic parameters (e.g., shoulder abduction) and muscle activation consistency during the drawing phase compared to novices. Differences in muscle activation were most pronounced in the flexor muscle groups. These findings highlight the critical role of movement consistency in archery performance. **Conclusion:** Greater consistency in kinematic and muscle activation patterns distinguishes higher-skilled archers, particularly during the drawing phase. These results emphasize the importance of targeting movement consistency and coordination in training programs to enhance performance in precision sports like archery.

Keywords: Archery, Shooting Consistency, Kinematic, EMG

1. Introduction

Archery is a precision sport characterized by its simple and stable movements, which are repetitively performed within a specified time to accumulate points. Therefore, it demands high stability in posture and excellent coordination across various body segments（Baifa et al., 2023 ; Leroyer et al., 1993）. As a traditional skill developed over thousands of years, archery was included as an official Olympic sport starting with the early 20th century Paris Olympics. Since the founding of the People's Republic of China, through the relentless efforts of successive generations, Chinese elite archers have started to excel in international competitions. For instance, Zhang Juanjuan won China's first Olympic gold medal in women's individual archery at the 2008 Beijing Olympics, which has progressively turned archery into a focal sport for China in the Olympics. Continuous breakthroughs in archery performance and its future development are closely linked to the underlying scientific research. An in-depth analysis of the biomechanical mechanisms of archery movements helps to better understand the technical demands placed on athletes, providing valuable insights for daily training planning.

Research in the field of sports biomechanics indicates that shooting consistency may be a key factor influencing whether athletes achieve excellent results （Quan et al., 2017 ; Stuart et al., 1990）. Shooting consistency refers to the degree of spatial consistency in the limb positions of an archer when repeating the archery movement after establishing a stable motor pattern. For example, Quan （Quan et al., 2017）used the Dynamic Time Warping (DTW) algorithm to analyze the shooting consistency of the draw arm among archers of four different skill levels. The study found that the shooting consistency of the draw arm positively correlates with the skill level, and the DTW distance of the acceleration curve of the draw arm can serve as a sensitive indicator for distinguishing archery skill levels. Given the precision required in archery techniques, it is challenging for coaches and researchers to capture subtle changes in an athlete’s movement in a short time. Consequently, many scholars have turned to electromyographic signals to more accurately reflect shooting consistency by analyzing the consistency of muscle activation between shots. Numerous electromyographic studies by Ertan’s research team（Shinohara et al., 2018 ; Ertan et al., 2011 ; Ertan, 2009 ; Soylu et al., 2006b ; Ertan et al., 2005b ; Ertan et al., 2003 ; Nishizono et al., 1987）have shown that the consistency of discharge in the upper limb muscle groups correlates positively with the skill level.

Although earlier studies showed the importance of shooting consistency on archery performance, the limited amount of these biomechanical researches has ever quantified the relationship between shooting consistency in terms of expertise level, while integrating analyses of electromyographic and kinematic data. Thus, the present study aims to provide a deeper understanding of the biomechanical foundations of shooting consistency, offering valuable insights for developing evidence-based training programs.

1.1 Participants

This study selected participants from the Chinese national team who trained between 2018 and 2020 in preparation for the 2020 Tokyo Olympics, including all team members (8 elite athletes). Additionally, 20 athletes from Chinese provincial teams were included (12 mid-level athletes and 8 novice athletes). All subjects were left-handed archers, meaning the left arm was used for holding the bow and the right arm for drawing. None of the participants had sustained upper limb injuries in the six months prior to testing.

Table 1 Means and standard deviations of age, weight, height, drawing weight and archery experience of the subjects.

Groups	Age	Heights (cm)	Weights (kg)	Drawing weights (lb)	Archery experience (year)
Elite (n=8)	19.6±3.8	175.1±7.6	77.6±9.1	46.3±4.8	4.9±2.0
Mid-level (n=12)	17.4±1.3	174.4±6.8	72.9±12.3	42.1±5.2	3.5±1.9
Novice (n=8)	16.0±1.3	175.0±10.1	72.1±13.7	42.3±4.2	2.2±0.8

1.2 Instruments

An eight-camera infrared high-speed motion capture system (Qualisys, Sweden, 200Hz) and a wireless surface EMG system (Delsys, USA, 2000Hz) were used to collect kinematic data and muscle activity in 8 trunk and upper extremity muscles. The following muscles on the draw arm side were recorded: middle trapezius (MTr), latissimus dorsi (LD), middle deltoid (MD), posterior deltoid (PD), long head of triceps brachii (LHT), biceps brachii (BB), extensor digitorum (ED), and flexor digitorum superficialis (FDS) muscles. Additionally, a high-speed motion camera (Qualisys, Sweden, 100Hz) was utilized to simultaneously capture video from the side to determine the moment of the archers' release.

1.3 Experimental Protocol

The test environment was a regular indoor training facility. Before the test began, basic information about the subjects was recorded. After being informed about the test procedure, subjects warmed up for 5 minutes wearing the same model of tight-fitting clothes. After warming up, a professional tester, using the upper limb model established by Rab（Rab et al., 2002）, attached 18 reflective markers (top of the head, seventh cervical vertebra, sternum, sacrum, both ear points, both acromion points, both coracoid processes, both radial styloids, both ulnar styloids, both third metacarpophalangeal joints, both anterior superior iliac spines) to the subjects. Additionally, three reflective markers were placed on the subjects' bows: above, below, and in front of the bow. The subjects then prepared in the testing area, and upon hearing the command, completed the archery motion test. The target was 30 meters away from the subjects. Coaches provided immediate feedback on the quality of each archery action. During the official test, each subject provided 12 valid data sets, resulting in a total of 336 valid data sets from 28 participants. Valid data are defined as those where the motion quality met the coaches' criteria and biomechanical parameters were fully captured.

1.4 Data Analysis

This study, integrating previous literature（Soylu et al., 2006a ; Ertan et al., 2005a） and the displacement characteristics of the bow and string, identified three characteristic moments in archery and divided them into two action phases. The Drawing Phase begins at the moment of bow drawing, defined as the point when the front of the bow reaches its highest vertical position, and ends at the bracing moment. The bracing moment is defined as the first frame in which the lateral point of the right elbow joint has a displacement of less than 0.5mm for at least five consecutive frames in the anterior-posterior direction. The Aiming Phase starts at the bracing moment and ends at the release moment. The release moment is determined by high-speed video synchronized with the action, defined as the moment when the arrow leaves the string.

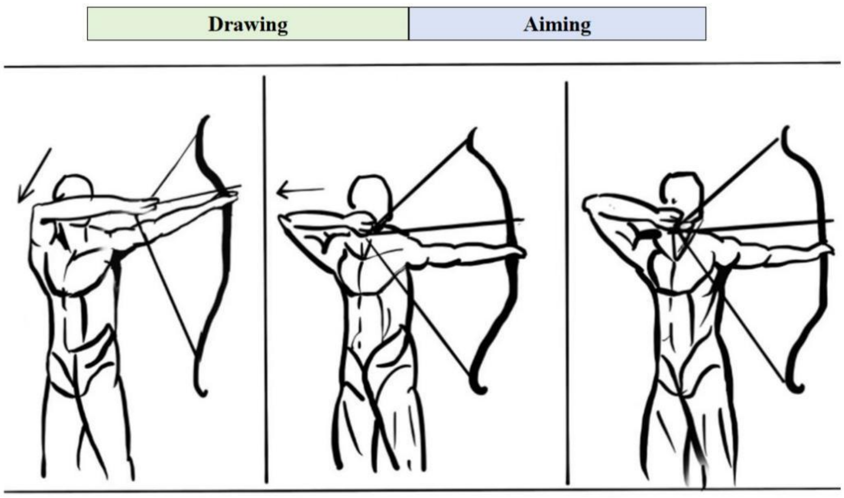

Figure 1. Illustration of a shooting cycle in an archer.

Kinematic variables were computed using Visual 3D software. A multi-rigid body model of the upper limb was established based on marker coordinates, and joint angles were calculated in three dimensions using Euler angles. For the draw arm, the coefficient of variation (CV) was calculated for the peak and trough values of the shoulder and elbow joint angles. Raw EMG signals were exported in CSV format using EMG works Analysis 4.3, then processed in MATLAB R2015b. A fourth-order Butterworth band-pass filter (5–450 Hz) was applied to the raw signals, followed by full-wave rectification to generate linear envelopes. The maximum value of each muscle's linear envelope across 12 shots was identified as the normalization reference. The integrated EMG (iEMG) was calculated for each muscle and phase, and its CV was computed for each phase across the 12 shots.

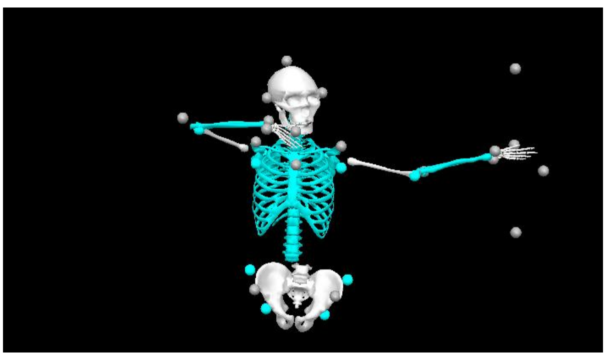

Figure 2. Establishment of a Human Model in Visual3D"

1.5 Statistical Analysis

One-way analysis of variance (ANOVA) was used to determine the differences in the coefficients of variation of kinematic variables and iEMG across different skill levels. The Least Significant Difference (LSD) method is employed for post-hoc testing, with the significance level set at α = 0.05. Data analysis is conducted using SPSS 20.0 software.

2 Results

Elite and mid-level athletes exhibited a significantly lower coefficient of variation in shoulder peak and trough abduction of the bow arm compared to novice athletes. No other significant differences were observed.

Table 2 Coefficients of variation for draw arm kinematic variables (%)

Variable	Elite	Mid-level	Novice
Elbow			
Peak extension	1.9±1.0	2.7±2.3	2.5±1.3
Trough extension	2.1±1.9	1.7±1.9	1.9±2.1
Shoulder			
Peak abduction	1.1±0.7♠	0.8±0.4♠	1.2±0.5
Trough abduction	1.0±0.6♠	0.8±0.4♠	1.5±0.8
Peak extension	3.2±4.5	2.5±3.1	2.1±1.8
Trough extension	18.5±61.5	15.7±50.6	28.5±77.8

Note: Following the LSD tests, comparisons with novice athletes are indicated by ♠ for $P < 0.05$, and comparisons with mid-level athletes are indicated by ♥ for $P < 0.05$

During the drawing phase, elite and mid-level athletes exhibited a significantly lower coefficient of variation in iEMG for the FDS, BB, PD, MD, and MTr on the draw arm compared to novice athletes. No other significant differences were observed.

Table 3 Coefficient of variation for iEMG of draw arm muscles (%)

Muscle	Elite	Mid-level	Novice
Drawing Phase			
FDS	9.8±5.8♠	10.7±3.5♠	20.5±16.5
ED	10.2±4.3	13.6±9.4	16.1±8.3
BB	10.0±2.7♠	13.0±4.0♠	21.9±11.2
LHT	14.2±14.0	11.5±4.0	17.8±12.1
PD	9.0±2.4♠	11.7±3.8♠	21.5±16.9
MD	9.4±4.2♠	13.1±3.9♠	23.5±17.0
LD	10.8±4.4	10.5±3.4	18.6±13.8
MTr	8.6±3.7♠	11.5±3.9♠	22.5±13.8
Aiming Phase			
FDS	46.3±12.8	54.8±18.8	46.5±27.5
ED	46.5±14.3	57.6±20.8	41.2±17.1
BB	46.8±9.9	58.0±18.9	43.4±21.7
LHT	51.7±22.4	57.1±18.5	62.9±49.7
PD	44.0±13.2	57.3±18.1	48.6±34.5
MD	43.7±12.1	57.4±18.8	48.3±28.9
LD	45.4±13.0	56.4±18.8	49.1±36.6
MTr	44.7±11.6	57.2±17.5	49.0±32.3

Note: Following the LSD tests, comparisons with novice athletes are indicated by ♠ for $P < 0.05$, and comparisons with mid-level athletes are indicated by ♥ for $P < 0.05$

4 Discussion

Movement consistency is crucial for enhancing proficiency and automating skills during the learning process（Preatoni et al., 2013）. Higher consistency not only ensures superior and stable performance outcomes （Burger et al., 2021） but also reduces the risk of sports injuries（Newell et al., 2009） . Newell posits that movement variability is an inherent noise within the human motor control system that not even elite athletes can eliminate during repeated technical actions. Representing a school of thought in motor control, Latash（Latash, 2012）argues that movement variability provides a margin of error that supports stable movement patterns and achievement of specific task objectives, reflecting the redundancy characteristics of human motor control. However, the dominant academic perspective maintains that increasing movement consistency during skill learning is crucial, especially in precision sports such as archery. Gentile's two-stage model of skill acquisition supports this viewpoint, suggesting that initial learning is based on trial and error, characterized by inefficient and inconsistent movements. As learners progress to an advanced stage, they can maintain high movement consistency and adapt to various task demands.

The coefficient of variation (CV) of biomechanical parameters during repeated movements typically measures movement consistency. Studies by Glanzer（Glanzer et al., 2019） on 47 baseball players showed that enhancing consistency in pitching motions significantly improved accuracy. Whiteside（Whiteside et al., 2016）analyzed kinematic data from 76,000 pitches by 190 Major League Baseball players, finding a strong correlation between the consistency of ball release positions and speeds with Fielding Independent Pitching (FIP) rates. Zhang（Zhang et al., 2014）compared successful and unsuccessful golf swings among 22 professional golfers, revealing that swings with poorer performance had less consistent kinematic parameters. Clarys（Clarys et al., 1990）conducted a study involving 15 Belgian archers of varying skill levels, who each shot three sets of six arrows. Surface electromyography (EMG) was collected from ten upper limb muscles during the shooting. The findings revealed that elite archers demonstrated higher consistency in muscle activation among the extensor digitorum, trapezius, and biceps brachii muscles. Our study found that, compared to novice archers, elite and mid-level archers exhibited smaller coefficients of variation (CVs) in both shoulder peak and trough abduction of the bow arm during shooting. These extremes correspond to the initial and final loading points of the draw, indicating more stable coordination between the bow and draw arms at these critical stages. This suggests that coaches should focus more on regulating and standardizing movements at these points when training novice athletes. This study also found that differences in muscle activation consistency among archers of varying skill levels were most pronounced during the drawing phase. Compared to novice archers, elite and mid-level archers demonstrated greater consistency in the activation of most muscles during this phase. These findings suggest that novice archers should prioritize training to improve activation consistency during the drawing phase. Coaches are advised to focus particularly on the flexor muscle groups of the draw limbs during training.

5 Conclusion

This study highlights significant differences in shooting consistency among archers of varying skill levels. Elite and mid-level athletes demonstrate superior kinematic and muscle activation consistency, especially during the drawing phase, compared to novices. These findings underscore the importance of stability and precise muscle coordination in achieving high performance, offering valuable guidance for evidence-based training programs.

6 Author’s contributions

B-FZ designed the study and wrote the manuscript; Z-CL searched for literature.

7 Funding

This work was supported by special fund project for basic research business expenses of the central universities of Southwest University in China (grant number SWU2309726).

8 Institutional Review Board Statement

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Beijing Sport University (protocol code 2020135H and approval date November 3, 2020). The study involved human participants, and informed consent was obtained from all subjects prior to participation.

9 Acknowledgments

We would like to thank staff and faculty at the school of sports at Southwest University.

10 Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

BAIFA Z, XINGLONG Z, DONGMEI L, 2023. Muscle coordination during archery shooting: A comparison of archers with different skill levels [J]. European Journal Of Sport Science, 23(1): 54-61.

BURGER B, WOLLNER C, 2021. The challenge of being slow: Effects of tempo, laterality, and experience on dance movement consistency [J]. Journal of Motor Behavior, 2021(8): 1-14.

ERTAN H, SOYLU A, KORKUSUZ F, 2005a. Quantification the relationship between FITA scores and EMG skill indexes in archery [J]. Journal Of Electromyography And Kinesiology, 15(2): 222-227.

ERTAN H, KNICKER A, SOYLU R, et al., 2011. Individual variation of bowstring release in high level archery: a comparative case study [J]. Human Movement, 12(3): 273-276.

GLANZER J A, DIFFENDAFFER A Z, SLOWIK J S, et al., 2019. The relationship between variability in baseball pitching kinematics and consistency in pitch location [J]. Sports Biomechanics, 20(7): 879-886.

LATASH M L, 2012. The bliss (not the problem) of motor abundance (not redundancy) [J]. Experimental Brain Research, 217(1): 1-5.

NISHIZONO H, SHIBAYAMA H, IZUTA T, et al., 1987. Analysis of archery shooting techniques by means of electromyography [C] //5 International Symposium on Biomechanics in Sports.364-372.

QUAN C-H, MOHY-UD-DIN Z, LEE S, 2017. Analysis of Shooting Consistency in Archers: A Dynamic Time Warping Algorithm-Based Approach [J]. Journal of Sensors, 2017(1): 7471217.

RAB G, PETUSKEY K, BAGLEY A, 2002. A method for determination of upper extremity kinematics [J]. Gait & posture, 15(2): 113-119.

SOYLU A, ERTAN H, KORKUSUZ F, 2006a. Archery performance level and repeatability of event-related EMG [J]. Human Movement Science, 25(6): 767-774.

STUART J, ATHA J, 1990. Postural consistency in skilled archers [J]. Journal Of Sports Sciences, 8(3): 223-234.

WHITESIDE D, MARTINI D N, ZERNICKE R F, et al., 2016. BALL SPEED AND RELEASE CONSISTENCY PREDICT PITCHING SUCCESS IN MAJOR LEAGUE BASEBALL [J]. Journal Of Strength And Conditioning Research, 30(7): 1787-1795.

ZHANG X, SHAN G, 2014. Where do golf driver swings go wrong? Factors influencing driver swing consistency [J]. Scandinavian Journal Of Medicine & Science In Sports, 24(5): 749-757.

CLARYS J P, CABRI J, BOLLENS E, et al., 1990. Muscular activity of different shooting distances, different release techniques, and different performance levels, with and without stabilizers, in target archery [J]. Journal Of Sports Sciences, 8(3): 235-257.

ERTAN H, KENTEL B, TUMER S T, et al., 2003. Activation patterns in forearm muscles during archery shooting [J]. Human Movement Science, 22(1): 37-45.

ERTAN H, SOYLU A R, KORKUSUZ F, 2005b. Quantification the relationship between FITA scores and EMG skill indexes in archery [J]. Journal Of Electromyography And Kinesiology, 15(2): 222-227.

ERTAN H, 2009. Muscular activation patterns of the bow arm in recurve archery [J]. Journal Of Science And Medicine In Sport, 12(3): 357-360.
LEROYER P, VAN HOECKE J, HELAL J N, 1993. Biomechanical study of the final push-pull in archery [J]. Journal Of Sports Sciences, 11(1): 63-69.
NEWELL K M, RANGANATHAN R, 2009. Some Contemporary Issues in Motor Learning [M] //D. STERNAD, Progress in Motor Control: A Multidisciplinary Perspective. Springer; New York: 395-404.
PREATONI E, HAMILL J, HARRISON A J, et al., 2013. Movement variability and skills monitoring in sports [J]. Sports Biomechanics, 12(2): 69-92.
SHINOHARA H, URABE Y, 2018. Analysis of muscular activity in archery: a comparison of skill level [J]. Journal Of Sports Medicine And Physical Fitness, 58(12): 1752-1758.
SOYLU A R, ERTAN H, KORKUSUZ F, 2006b. Archery performance level and repeatability of event-related EMG [J]. Human Movement Science, 25(6): 767-774.