Bow oscillation and its association with shooting accuracy in junior elite recurve archers

Oscilación del arco y su relación con la precisión en tiradores junior de élite de arco recurvo

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Abstract

Introduction and Objective: Bow stability before release is a key determinant of precision, yet its relationship with upper-limb strength in junior elite archers remains under-characterized. This study aimed to quantify triaxial bow oscillation and examine its association with shooting performance and maximal isometric handgrip strength.
Methodology: Using an 8-camera Vicon system, 3D kinematics were recorded to evaluate bow displacement and pulling-hand variability during a standardized pre-release window in recurve archers.
Results: Longitudinal oscillation was identified as the most consistent kinematic determinant of performance, showing a large negative association with shooting score. A nearly perfect negative correlation was found between mean score and grouping area (minimum enclosing circle method). While handgrip strength was not associated with performance, bow draw force showed a moderate-to-large positive association with score, though it did not reach statistical significance after correction.
Conclusions:These findings highlight the critical role of longitudinal stability over raw hand strength in determining shooting precision among elite junior recurve archers.

Keywords

Archery; biomechanics; bow stability; motion capture; pre-release phase.

Resumen

Introducción y Objetivo: La estabilidad del arco antes del lanzamiento es un factor clave para la precisión; sin embargo, su relación con la fuerza del miembro superior en arqueros júnior de élite apenas ha sido caracterizada. El objetivo de este estudio fue cuantificar la oscilación triaxial del arco y examinar su asociación con el rendimiento de tiro y la fuerza isométrica máxima de prensión manual.
Metodología: Mediante un sistema Vicon de 8 cámaras, se registró la cinemática en 3D para evaluar el desplazamiento del arco y la variabilidad de la mano de tiro durante un intervalo estandarizado previo al suelte en arqueros de arco recurvo.
Resultados: La oscilación longitudinal se identificó como el determinante cinemático más consistente del rendimiento, mostrando una gran asociación negativa con la puntuación. Asimismo, se halló una correlación negativa casi perfecta entre la puntuación media y el área de agrupación (método del círculo mínimo envolvente). Mientras que la fuerza de prensión manual no se asoció con el rendimiento, la fuerza de apertura del arco mostró una asociación positiva de moderada a alta con la puntuación, aunque sin alcanzarse significación estadística tras la corrección.
Conclusiones: Estos hallazgos destacan el papel crítico de la estabilidad longitudinal por encima de la fuerza bruta de la mano al determinar la precisión del tiro en arqueros júnior de élite.

Palabras clave

Biomecánica; captura de movimiento; estabilidad del arco; fase previa al lanzamiento; tiro con arco.

Introduction

Archery is a sport in which competitive performance is determined by the capacity to repeatedly deliver arrows to a fixed target under tightly controlled biomechanical conditions. Recurve modality has been the style used at the Olympic Games since archery's reintroduction in 1972 (World Archery, n.d.) and, from a mechanical standpoint, imposes greater demands on the athlete than compound, since the string must be drawn and released with the fingers and the full draw load, often exceeding 20 kg. Elite recurve performance has been described as requiring extreme precision combined with substantial upper-body strength and endurance (Spratford & Campbell, 2017).

The shooting technique in recurve archery is commonly conceptualized as a highly repeatable sequence of phases. Existing frameworks range from three (Leroyer, Van Hoecke, & Helal, 1993) up to six phases used in biomechanical research (Nishizono, Shibayama, Izuta, & Saito, 1987; Ertan, Kentel, Tümer, & Korkusuz, 2003), being the final segment of the cycle consistently identified as the most performance relevant. During this period the archer must sustain near-maximal isometric loading of the drawing musculature while preserving the alignment between arrow, string and target (Abekura et al., 2025; Edelmann-Nusser, Heller, Hofmann, & Ganter, 2006).

Within this final segment, fine kinematic control of the bow has been repeatedly highlighted as a key determinant of accuracy. Reduced bow movement during the aiming phase has been associated with improved shooting performance in recurve archery (Sarro et al., 2021), while complementary evidence indicates that postural stability, assessed through center-of-pressure measures, may also contribute to shooting performance (Tinazci, 2011; Spratford & Campbell, 2017). Direct comparisons between elite and sub-elite recurve archers have shown that smaller pre-release displacements of the bow co-occur with higher shooting scores, supporting bow stability as a discriminative biomechanical marker of expertise (Quan & Lee, 2016). In the same direction, a recent systematic review confirmed that body and equipment stability variables consistently relate to performance (Santos, Barreto, Atalaia, & Aleixo, 2025).

Beyond stability per se, contemporary motor-control perspectives emphasize that skilled performance does not require the elimination of movement variability but rather its functional regulation, with task-relevant degrees of freedom being constrained while less critical components retain flexibility (Bartlett, Wheat, & Robins, 2007; Jacquot, Ben Mansour, Bouillet, Jehl, & Gauchard, 2025). Applied to archery, this framework suggests that the spatial axes along which oscillation is most tightly controlled may not be uniformly distributed across the vertical, lateral and longitudinal directions of bow motion. However, recent methodological appraisals of performance assessment in archery have noted that most prior biomechanical studies have either focused on global postural or equipment stability without disaggregating bow motion by axis or have relied on instrumentation with limited spatial accuracy (Ahmad et al., 2014; Vendrame et al., 2022). High-resolution optical motion capture, although considered the gold standard for indoor three-dimensional kinematic analysis, has been comparatively underused in target archery research and, in particular, in junior elite populations.

Regarding physical determinants, upper-limb strength has traditionally been considered relevant to performance owing to the magnitude and duration of the isometric load required to maintain full draw (Spratford & Campbell, 2017). Maximal isometric handgrip strength, a widely used and low-burden index of upper-limb strength, has been proposed as a candidate predictor in this context, but the evidence regarding its specific association with shooting accuracy in trained recurve archers remains limited and inconsistent.

Taken together, these issues remain incompletely addressed in the current literature.

Hypothesis

The aim of the present study is to investigate the relationship between pre-release bow kinematic stability and shooting performance in junior elite recurve archers and to examine whether maximal isometric handgrip strength is related to bow stability and overall shooting outcomes. It is hypothesized that (i) greater pre-release bow oscillation would be associated with lower shooting score and larger impact dispersion, with the strongest associations occurring along the axis most directly aligned with the bow–string–arrow vector, and (ii) maximal handgrip strength would show only weak associations with performance outcomes in this trained population.

Regarding physical determinants, upper-limb strength has traditionally been considered relevant to performance owing to the magnitude and duration of the isometric load required to maintain full draw. However, maximal isometric handgrip strength represents a relatively general measure of distal upper-limb force capacity and does not directly reproduce the muscular demands of the full-draw position, which rely predominantly on the scapulothoracic stabilizers, posterior shoulder complex and drawing-arm musculature. Indeed, draw-specific force capacity has been associated with performance in elite recurve archers (Spratford & Campbell, 2017), whereas evidence concerning handgrip strength as an independent determinant of shooting accuracy remains limited and inconsistent. Therefore, in highly trained archers who have presumably exceeded the minimum grip-strength requirements needed to manipulate the bow effectively, maximal handgrip strength may provide limited discriminatory value for shooting performance.

Method

Participants

Eight junior elite recurve archers (5 males, 3 females; age 17 ± 3 years; height 168 ± 10 cm) participated in this cross-sectional study. Individual characteristics and equipment specifications are presented in Table 1.

Table 1. Participant´s characteristics

nº	Height (cm)	Age (years)	Pulling hand	Riser (manufacturer/ model)	Limbs (manufacturer/model/power)
1	158	21	R	WIN&WIN ATF-X 25"	W&W-NSG66"-50LBS
2	157,5	18	R	WIN&WIN ATF-DX 25"	W&W-NSXP66"-48LBS
3	169	15	R	HOYT GMX 3	HOYT-AXIA68"-44LBS
4	160	14	R	HOYT GMX 3	W&W-NS66"-36LBS
5	171	14	R	HOYT GMX 3	W&W-NS68"-36LBS
6	155	16	R	HOYT XCEED	HOYT-VELOS66"-38LBS
7	174	18	L	HOYT XD	HOYT-AXIA70"-44LBS
8	178	17	R	HOYT GMX 3	HOYT-AXIA68"-44LBS

R: Right hand, L: left hand

All participants were affiliated with the Federación Madrileña de Tiro con Arco. Inclusion criteria required (i) at least four years of structured training and competitive experience at national and/or international level, (ii) a minimum weekly training volume of ≥ 6 h/week and (iii) absence of any musculoskeletal injury, pain or neurological disorder during the six months prior to testing. Exclusion criteria comprised acute illness on the day of assessment, recent modification of bow set-up (within the previous two weeks) and inability to complete the protocol with their habitual competition equipment. Female participants were tested independently of menstrual cycle phase, which was recorded but not used as a stratification variable. The eight participants represent a substantial fraction of the federated junior elite population at this competitive level within the study region. Participants and, when applicable, their legal guardians, provided written informed consent. The study was approved by the Research Ethics Committee of Universidad Europea de Madrid and conducted in accordance with the Declaration of Helsinki and applicable Spanish and European data-protection regulations (Regulation (EU) 2016/679; Ley Orgánica 3/2018).

Design

This single-session, laboratory-based, cross-sectional observational study followed STROBE recommendations (von Elm et al., 2007) and was conducted in the Human Performance Research Laboratory of Universidad Europea de Madrid, where an 8-camera optical motion-capture system (Vicon Vantage V5; Vicon Motion Systems Ltd., Oxford Metrics, UK) is permanently installed. Trials were performed indoors at 18 m, aligned with World Archery indoor competition specifications, with ambient temperature 20–24 °C and relative humidity 40–60 %, and scheduled in the morning (10:00–13:30 h) to control for diurnal variation in neuromuscular performance.

Procedure

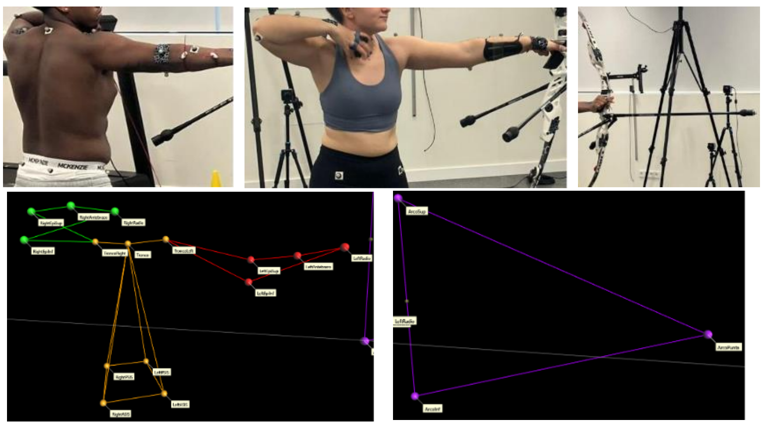
Participants refrained from intense exercise for 24 h, from caffeine and ergogenic substances for 12 h, and maintained habitual sleep and nutritional patterns for 48 h before testing. Each archer was evaluated individually in a single ~30-min session structured in four blocks. First, demographic, anthropometric and bow-equipment data were recorded. Second, maximal isometric handgrip strength was assessed bilaterally with a calibrated digital hand dynamometer (Takei TKK 5401; Takei Scientific Instruments Co., Niigata, Japan) following standardized guidelines (Roberts et al., 2011): two 3–5 s maximal voluntary contractions per hand, separated by 60 s of recovery, with the peak value retained. Third, maximal bow draw force was measured during full opening to the individual habitual draw length using a calibrated digital dynamometer (PCE-FM1000; PCE Instruments, Meschede, Germany), with three trials per archer separated by 60 s of recovery; the mean of the three trials was retained. Fourth, after an individualized competition-like warm-up (mobilization plus 12 progressive shots at the testing distance), the motion-capture workflow was executed. Each participant then performed two series of six consecutive arrows at 18 m, separated by 3–5 min of passive recovery. Each arrow was recorded as an individual trial. Target score was documented arrow-by-arrow and high-resolution images of the target face were captured for offline quantification of impact dispersion.

The primary outcome variables derived from this protocol were: maximal isometric handgrip strength (kg), bow draw force (lb), mean shooting score (points per arrow), grouping area (cm^2) and bow and upper-limb kinematic variables extracted from motion capture.

Equipment, marker set and bow tracking

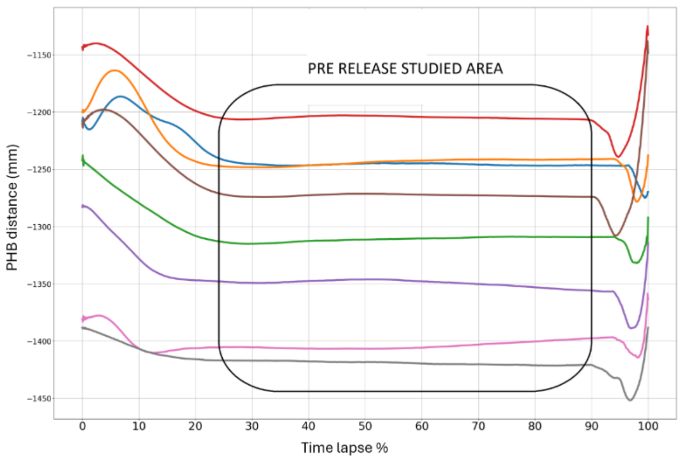
Archers shot using their own habitual competition equipment in order to preserve individual technical adaptation; no modifications were introduced for the study. Three-dimensional kinematic data were collected at 120 Hz with the Vicon Vantage V5 system over a calibrated capture volume (~4 × 4 × 2,5 m). A total of 18 retro-reflective passive markers (14 mm diameter) were attached using double-sided tape. The 15 on the participant following a modified Plug-in Gait full-body model adapted to archery posture (Kadaba et al., 1990; Davis et al., 1991; Landlinger et al., 2010) as follow: bilateral anterior and posterior superior iliac spines (R/L ASIS, R/L PSIS), seventh cervical vertebra (C7), lateral border of each acromion (R/L acromion), medial and lateral epicondyles of both elbows (R/L medial and lateral epicondyle), midpoint between elbow and wrist on each forearm (R/L mid-forearm) and radial styloid process of each wrist (R/L radial styloid). The 3 markers on the bow (upper end of the long-rod stabilizer, bow grip, and lower limb tip) were to characterize the bow as a rigid body (Figure 1). Markers were placed by a single experienced researcher (ISAK Level 3) in all participants. The global coordinate system was defined with the X-axis pointing antero-posteriorly (towards the target), Y-axis medio-lateral and Z-axis vertical.

Figure 1, Set of images with the markers placed on the bow and according to the alternative Plug-in Gait full body model (Vicon, Oxford Metrics, Oxford, UK), Left Top: posterior view, Middle Top: anterior view, Right Top: bow, Left bottom: 3D model of the person with the 15 markers, Right bottom: 3D model of the bow with the 3 markers



Bow oscillation was computed as the displacement of the mid-point between the bow markers, decomposed into three orthogonal components: vertical (Z), lateral (Y) and longitudinal/antero-posterior (X). For each axis and trial, the pre-release period was identified from the time course of the pulling-hand–to–bow (PHB) distance. The preceding drawing/bow-lowering phase was characterized by a progressive change in PHB distance, whereas the release transition was identified by the abrupt departure from the near-steady PHB pattern associated with the onset of post-release bow motion. A fixed 5 seconds window entirely contained within the intervening near-steady period was then selected for analysis. The 5 seconds duration was not intended to define the physiological or technical duration of the aiming phase; rather, it provided a standardized observation interval of identical duration across participants and trials while avoiding the preceding drawing transition and the subsequent release-related movement. Bow oscillation amplitude along each axis was calculated exclusively within this window (Figure 2). The mean ± standard deviation across the 12 arrows was retained for each participant. PHB distance variability during the pre-release window was computed as an additional kinematic descriptor.

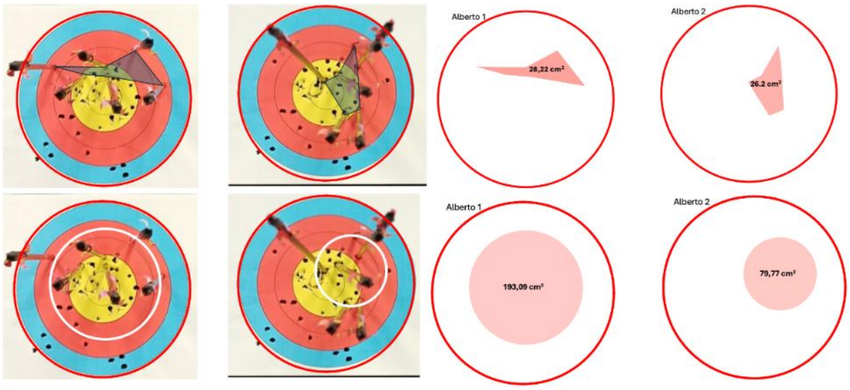
Figure 2. Pulling-hand–to–bow (PHB) distance used for temporal segmentation of the shooting cycle. The standardized 5 seconds analysis window was selected within the near-steady pre-release period, after completion of the drawing/bow-lowering transition and before the abrupt kinematic change associated with release. The shaded region therefore represents the analytical interval used to quantify bow oscillation and does not represent the entire duration of the aiming phase.



Arrow grouping and scoring

After each six-arrow series, a high-resolution image of the target face was acquired with a tripod-mounted camera positioned perpendicular to the target plane at 2 m, with the optical axis aligned with the target center. Spatial calibration was based on the visible outer diameter of the 25-cm target face. Arrow grouping was quantified as the area of the minimum enclosing circle containing the six impact points, determined using the Welzl algorithm (Welzl, 1991), and expressed in cm^2 (Figure 3). Target score was recorded arrow-by-arrow according to the standard indoor 18 m scoring system, and the mean across the 12 arrows was retained as the individual performance outcome.

Figure 3. Example of determination of arrow impact dispersion area on the target face, illustrating the two steps used in the present study: the convex hull (polygonal envelope enclosing the six impact points) and the minimum enclosing circle obtained by Welzl's algorithm applied to the vertices of the convex hull. Spatial calibration was performed using the visible outer diameter of the 25-cm red target face (≈ 358,5 px in the original image frame). Dispersion areas derived of both steps are expressed in cm².



Statistical analysis

Given the nature of the study and the structurally limited size of the target population, the statistical approach was designed to emphasize estimation of effect size and associated uncertainty, complemented by inferential statistics. Descriptive data are presented as mean ± SD. Normality was examined with the Shapiro–Wilk test. Because several variables departed from normality, associations between performance outcomes (mean shooting score) and kinematic and physical variables (vertical, lateral and longitudinal bow oscillation amplitudes; PHB variability; maximal handgrip strength; bow draw force) were quantified using Spearman's rank correlation coefficient (ρ). Correlation magnitudes were interpreted according to Hopkins et al. (2009) as trivial (|ρ| < 0.10), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89) and nearly perfect (≥ 0.90). To account for multiple comparisons, raw p-values were complemented with values adjusted by the Benjamini–Hochberg false discovery rate procedure (Benjamini & Hochberg, 1995); the significance threshold was set at p_BH < 0.05. For each correlation, 95 % confidence intervals were estimated with Fisher's z-transformation. A pre-specified sensitivity analysis was conducted excluding participants showing standardized values of |z| ≥ 2.5 in two or more primary outcomes; under this criterion, archer #3 was identified as a multivariate outlier and the analyses were repeated on n = 7.

Results

Descriptive statistics for all study variables are presented in Table 2. In the full sample, mean shooting score across the 12 recorded arrows was 8,70 ± 1,15 points (range 6,00–9,50), mean grouping area was 103,4 ± 129,4 cm^2 and mean handgrip strength (averaged across right and left hand) was 30,50 ± 7,08 kg. Mean pre-release bow oscillation amplitudes were 8,56 ± 5,67 mm, 5,30 ± 3,38 mm and 6,65 ± 4,72 mm in the vertical, lateral and longitudinal axes, respectively. Application of the a priori outlier criterion (|z| ≥ 2,5 in two or more primary outcomes) identified archer #3 as a single multivariate outlier, displaying simultaneously the lowest mean shooting score (6,00 points) and the highest values of dispersion area (384,1 cm^2), vertical (20,72 mm), lateral (11,48 mm) and longitudinal (16,57 mm) bow oscillation. After exclusion, mean shooting score increased to 9,08 ± 0.41 points, the mean grouping area decreased to 68,4 ± 36,8 cm^2, and mean oscillation amplitudes decreased to 6,83 ± 3,06 mm (vertical), 4,42 ± 2,47 mm (lateral) and 5,24 ± 2,70 mm (longitudinal), illustrating the disproportionate influence of this single observation. The Shapiro–Wilk test indicated departures from normality for shooting score, grouping area, PHB variability and longitudinal oscillation supporting the use of rank-based correlation as the primary inferential approach.

Table 2. Data for the 12 recorded arrows.

nº	HG RH (kg)	HG LH (kg)	Draw force (lb)	Mean score	Arrows mean dispersion (cm^2). Mean [SD]	Pulling hand-bow variation dpr (mm). Mean [SD]	Vertical oscillation dpr (mm). Mean [SD]	Lateral oscillation dpr (mm). Mean [SD]	Longitudinal oscillation dpr (mm). Mean [SD]
1	23,5	23,5	42,4	9,33	55,1 [8,2]	9,40 [2,24]	8,79 [2,19]	4,04 [0,94]	8,96 [2,74]
2	18,5	21,5	39,3	9,50	34,0 [14,2]	7,14 [1,36]	7,78[1,58]	7,32 [1,35]	3,15 [0,99]
3	33	35	41,8	6,00	348,1 [297,7]	6,37 [1,17]	20,72 [4,87]	11,48 [3,57]	16,57 [5,94]
4	27,5	28,5	31,5	8,33	136,4 [80,1]	23,64 [6,81]	3,97 [0,90]	1,96 [0,58]	9,26 [2,39]
5	36,5	33	33,5	9,25	47,2 [21]	8,96 [1,67]	11,12 [2,50]	3,52 [0,97]	4,05 [1,21]
6	29	23,5	36	8,75	90,8 [11,6]	22,39 [5,37]	4,45 [1,04]	6,59 [1,91]	4,45 [0,83]
7	38,5	40,5	47,8	9,33	35,7 [18,9]	9,24 [2,50]	2,92 [0,56]	6,53 [1,57]	3,94 [1,26]
8	37,5	38,5	43,5	9,08	79,9 [43,5]	5,77 [1,75]	8,77 [1,75]	0,97 [0,24]	2,84 [0,72]

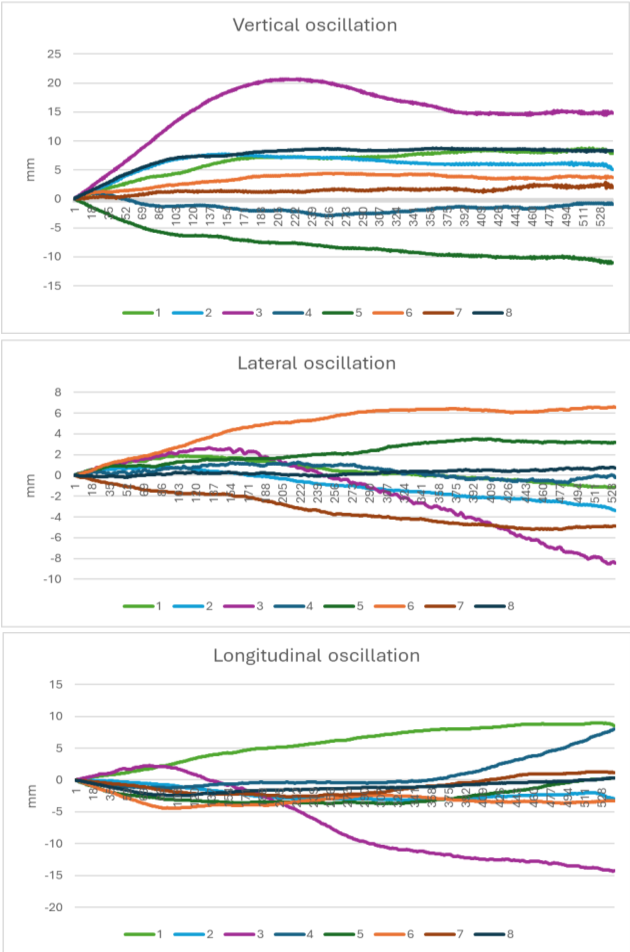
HG: Handgrip strength; RH: right hand; LH: left hand; dpr: during pre-release. Values are reported as mean [standard deviation] across the 12 recorded arrows per participant.

Individual level pre-release time series of PHB distance and bow displacement along the three orthogonal axes are illustrated in Figures 4 and 5, respectively. Visual inspection of Figure 4 shows that the inter-individual differences in absolute PHB distance (range approximately 770–1000 mm) reflect anthropometric and equipment differences across participants, while within-trial variation during the analyzed 5 seconds window remained generally small and continuously increasing.

Figure 4. Time course of the distance between the radial styloid marker of the drawing wrist and the bow grip marker (pulling-hand–to–bow distance, mm) during the 5 s pre-release window. X axis values show the video frame at 120 Hz acquisition rate. Colors identify individual archers (1–8).

Figure 5 illustrates the heterogeneity of pre-release bow oscillation patterns across the three spatial axes: vertical and longitudinal trajectories of archer #3 (purple line) clearly diverge from the rest of the sample, drifting beyond ±15 mm in both axes, whereas the remaining seven participants exhibited substantially smaller and more bounded displacements (typically within ±10 mm).

Figure 5. Three-dimensional bow displacement during the 5 s pre-release window for each participant, decomposed into vertical (top), lateral (middle) and longitudinal/antero-posterior (bottom) components in the laboratory global coordinate system, Trajectories were referenced to zero at the onset of the analyzed interval. X axis values show the video frame at 120 Hz acquisition rate. Colors identify individual archers (1–8).



Spearman correlations with 95 % CI, raw p-values and Benjamini–Hochberg–adjusted p-values are reported in Table 3 for both the primary (n = 8) and the sensitivity (n = 7) analyses. A nearly perfect negative association was observed between mean shooting score and grouping area in the primary analysis ($\rho = -0.96$; 95 % CI [−0.99, −0.78]; $p < 0.001$; $p_{BH} = 0.0011$), which reached statistical significance after correction and remained robust in the sensitivity analysis ($\rho = -0.94$; $p_{BH} = 0.011$). The association between shooting score and longitudinal bow oscillation was of large magnitude in both analyses ($\rho = -0.68$ and $\rho = -0.52$, respectively), in the hypothesized direction, although neither survived FDR correction. Correlations between shooting score and vertical or lateral oscillations were of trivial-to-small magnitude in the primary analysis and showed sign reversal or substantial change after exclusion of archer #3, reflecting high sensitivity to individual observations. Maximal handgrip strength was not associated with shooting score ($\rho = -0.19$ and $\rho = -0.23$ for n = 8 and n = 7, respectively). Bow draw force showed a positive association with shooting score that increased from moderate ($\rho = 0.36$) in the primary analysis to large magnitude ($\rho = 0.54$) in the sensitivity analysis, with directional consistency across both configurations, although it did not reach statistical significance after FDR adjustment.

Table 3. Spearman rank correlation coefficients (ρ) between performance outcomes and kinematic and physical variables in the primary (n = 8) and sensitivity (n = 7, archer #3 excluded) analyses. 95 % confidence intervals were estimated. p-values are reported both unadjusted (p) and adjusted by the Benjamini–Hochberg false discovery rate procedure (p_BH).

Variable pair	n	ρ	95 % CI	p	p_BH	Magnitude
			Score correlations			
Score × Grouping area	8	−0,96	[−0,99, −0,78]	<0,001	0,0011	nearly perfect
	7	−0,94	[−0,94, −0,63]	0,002	0,011	nearly perfect
Score × Vertical oscillation	8	−0,20	[−0,79, +,59]	0,629	0,943	small
	7	0,20	[−0,63, 0,91]	0,670	0,792	small
Score × Lateral oscillation	8	0,04	[−0,69, 0,72]	0,933	0,933	trivial
	7	0,56	[−0,34, 0,92]	0,192	0,577	large
Score × Longitudinal oscillation	8	−0,68	[−0,94, 0,04]	0,062	0,186	large
	7	−0,52	[−0,92, 0,38]	0,23	0,229	large
Score × PHB variation	8	−0,08	[−0,75, 0,66]	0,844	0,943	trivial
	7	−0,52	[−0,92, 0,38]	0,229	0,401	large
Score × Handgrip strength	8	−0,19	[−0,79, 0,59]	0,649	0,799	small
	7	−0,23	[−0,84, 0,63]	0,613	0,736	small
Score × Bow draw force	8	0,36	[−0,46, 0,85]	0,382	0,764	moderate
	7	0,54	[−0,36, 0,92]	0,210	0,421	large

Discussion

The aim of this study was to examine the relationship between pre-release bow kinematic stability and shooting performance in junior elite recurve archers, and to assess whether maximal isometric handgrip strength and bow draw force were related to bow stability and overall shooting outcomes. The main findings can be summarized as follows. First, grouping area quantified by the minimum enclosing circle method exhibited a nearly perfect negative association with shooting score that survived correction for multiple comparisons in both the primary and sensitivity analyses, validating dispersion area as a robust complementary indicator of shooting precision in this population. Second, longitudinal bow oscillation showed a large negative association with score in both analyses. Third, neither maximal isometric handgrip strength nor bow draw force was significantly associated with shooting score after FDR adjustment, although bow draw force showed a positive association of moderate-to-large magnitude with shooting score that was directionally consistent across both sample configurations.

Although the score-related coefficients did not reach statistical significance after FDR correction, their magnitude, directional consistency and biomechanical plausibility, together with the very strong dispersion-related findings, support the longitudinal axis as a primary target for technique-oriented training and performance monitoring in recurve archery. These results are consistent with previous observations in recurve archery (Sarro, Viana, & de Barros, 2021; Quan & Lee, 2016) and with evidence from other static-aim disciplines, where the axis aligned with the projectile trajectory has been identified as particularly performance-relevant (Ball, Best, & Wrigley, 2003; Konttinen, Landers, & Lyytinen, 2000; Mononen, Konttinen, Viitasalo, & Era, 2007). The comparatively weaker associations observed along the vertical and lateral axes are consistent with the notion that recurve archers preferentially constrain variability in task-relevant directions while tolerating greater flexibility in less critical components of bow motion (Bartlett, Wheat, & Robins, 2007).

Another relevant observation concerns the differential pattern observed between maximal isometric handgrip strength and bow draw force in relation to shooting performance. Whereas handgrip strength —a global index of distal upper-limb force production— was unrelated to shooting score, bow draw force exhibited a positive association of moderate-to-large magnitude with mean shooting score across both analyses (ρ = 0.36 in the primary analysis and ρ = 0.54 in the sensitivity analysis). This dissociation is mechanistically coherent with the muscular architecture of recurve shooting: the capacity to draw and sustain the bow at full opening depends primarily on the force-generating capacity of the scapulothoracic stabilizers, the posterior shoulder complex and the drawing-arm retractors rather than on grip strength per se, and ultimately determines the maximum limb poundage that an archer can safely manage while preserving repeatable technique during prolonged competition. The capacity to sustain higher draw forces has, in turn, been associated with superior performance in elite recurve archery (Spratford & Campbell, 2017), in line with the present observations. Within the limits imposed by the design and the absence of statistical significance after FDR correction, these findings suggest that draw-specific force capacity, rather than generic upper-limb strength, may be the more relevant physical determinant of competitive shooting outcomes in trained recurve archers.

An important methodological observation emerging from the present investigation concerns the influence of the dispersion metric on the structure of the observed correlations. The minimum enclosing circle method (Welzl algorithm), adopted here as the primary operationalization of arrow grouping, yielded a biomechanically coherent pattern: a strong negative association between grouping area and shooting score. Future investigations examining arrow grouping in recurve archery should report dispersion under multiple operationalizations (e.g., convex hull, minimum enclosing circle, centroid-based radial error) and should critically evaluate their convergent validity before interpreting correlational findings (Jacquot, Ben Mansour, Bouillet, Jehl, & Gauchard, 2025).

Limitations

The most substantial limitation concerns sample size. The eight junior elite recurve archers represent a sizeable fraction of the available federated population at this competitive level within the study region, but the resulting statistical power was insufficient to test inferential hypotheses with high confidence beyond the dispersion-related association. The wide 95 % CIs reported in Table 3 are compatible with a broad range of underlying correlations, and several coefficients reversed in sign or changed substantially after exclusion of a single multivariate outlier. The findings should therefore be regarded as effect-size estimates of value to inform the design of larger confirmatory studies, rather than as definitive evidence of established biomechanical associations.

Practical implications

The pattern of preliminary findings offers tentative orientations for coaches and applied practitioners working with junior elite recurve archers. The candidate role of longitudinal (antero-posterior) bow oscillation as the axis most closely coupled with shooting accuracy suggests that technical training during the late aiming phase may benefit from targeted feedback on anterior–posterior bow stability rather than on global indices of bow steadiness. The lack of association between maximal handgrip strength and shooting performance further indicates that, in trained archers who have surpassed the minimum strength threshold required to control the bow, training emphasis may be more productively allocated to fine motor control, coordination and repeatability of the final phase of the shooting cycle than to increases in gross force capacity. Motion-capture systems and increasingly wearable inertial sensors validated against optical reference systems (Vendrame et al., 2022) may represent useful complementary tools for individualized technical training.

Maximal bow draw capacity in recurve archery depends primarily on the force-generating capacity of the scapulothoracic stabilizers, the posterior shoulder complex and the drawing-arm retractors rather than on grip strength per se, and this capacity determines the maximum limb poundage that an archer can safely manage while preserving repeatable technique during prolonged competition. The moderate to large positive association between bow draw force and shooting score, together with the mechanical considerations discussed above, supports the inclusion of targeted resistance training programs aimed at increasing strength and local muscular endurance of the drawing musculature. Such interventions have been shown to be feasible and effective in archers, with reported improvements in shoulder and scapular strength, shooting stability and performance indices after structured programs combining general resistance training and archery-specific drills (Ertan, 2009; Shinohara & Urabe, 2018). Progressive increases in bow poundage may thus be a legitimate training target, provided that any increase in equipment demand is matched by preserved technical consistency during the final phase of the shooting cycle.

Conclusions

In junior elite recurve archers, longitudinal pre-release bow oscillation emerged as the kinematic axis most consistently linked to shooting accuracy, while grouping area quantified by the minimum enclosing circle showed a nearly perfect negative association with shooting score that was robust to multivariate outlier exclusion. Bow draw force, but not maximal isometric handgrip strength, showed a directionally consistent positive association with score. These findings point to anterior–posterior bow control and draw-specific force capacity as priority targets for technical and physical preparation in this population.

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