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Phase-Specific Kinematic Characteristics and Movement Organization in Female Artistic Gymnastics Vault: An Exploratory Video-Based Case Analysis

Dini Aquylaria Sari[1]*, Achmad Widodo[1], Fransisca Januarumi M W[1], Irmantara Subagio[1], Heri Wahyudi[1], Pudjijuniarto[1]

[1]Faculty of Sports Science and Health, Surabaya State University, Indonesia.

EDITED BY
Dr. Joel Paul
University of Trinidad and Tobago, Trinidad and Tobago.

*CORRESPONDENCE
Dini Aquylaria Sari
diniaquylariasari@gmail.com

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Dini Aquylaria Sari
Achmad Widodo
Fransisca Januarumi M W
Irmantara Subagio
Heri Wahyudi
Pudjijuniarto

ABSTRACT

Background & objective: Vault performance in women's artistic gymnastics requires the coordinated organization of high-velocity movement across successive phases, from the approach run to the second flight. Previous biomechanical research has frequently examined individual variables in isolation, whereas phase-specific coordination across the complete vault sequence remains less explored using accessible video-based methods. This study aimed to explore phase-specific kinematic characteristics and inter-phase movement organization among selected female artistic gymnasts competing at Olympic/international and national levels.

Materials & Methods: An exploratory multiple-case study design was employed using retrospective video-based biomechanical analysis. Five female gymnasts were analyzed, comprising three Olympic/international-level and two national-level athlete-performance cases. Publicly available competition footage was analyzed frame-by-frame using Kinovea motion-analysis software. Eleven kinematic variables were examined across the run-up, first-flight, repulsion, and second-flight phases, including run-up speed, hip and bilateral knee angles, hand-contact duration, bilateral elbow angles, second-flight elevation, flight duration, and bilateral knee angles. Descriptive statistics were calculated using means, standard deviations, minimums, maximums, and between-group mean differences. Intra-rater measurement reliability was assessed using ICC(2,1), 95% confidence intervals, SEM, MDC95, and Bland–Altman agreement analysis.

Results: The national-level cases demonstrated higher mean run-up speed (7.95 ± 2.62 vs. 7.47 ± 2.23 m/s) and second-flight elevation (2.95 ± 0.03 vs. 2.57 ± 0.21 m). Olympic/international cases demonstrated greater first-flight knee extension, particularly in the right knee (175.17 ± 1.85 vs. 154.75 ± 1.20°), and slightly longer second-flight duration (0.89 ± 0.10 vs. 0.84 ± 0.09 s). All repeated kinematic measurements demonstrated excellent intra-rater reliability, with ICC values ranging from 0.997 to 1.000.

Conclusions: The findings indicate that vault execution cannot be adequately characterized by a single kinematic variable. The international contribution of this study lies in proposing a phase-integrated video-analysis perspective in which approach velocity, body configuration, table interaction, and second-flight organization are interpreted as interconnected components of vault technique. The findings provide preliminary biomechanical evidence for future standardized and three-dimensional investigations of inter-phase movement coordination.

Keywords
artistic gymnastics; vault; kinematics; biomechanics; video analysis; movement coordination.

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INTRODUCTION

Global and Theoretical Context
Critical Review of Existing Evidence
Research Gap, Novelty, and International Contribution
Objectives

MATERIALS AND METHODS

Study Design
Selection and Video Sources
Video Data and Analysis Procedure
Kinematic Variables
Data Analysis
Anatomical Landmark Identification

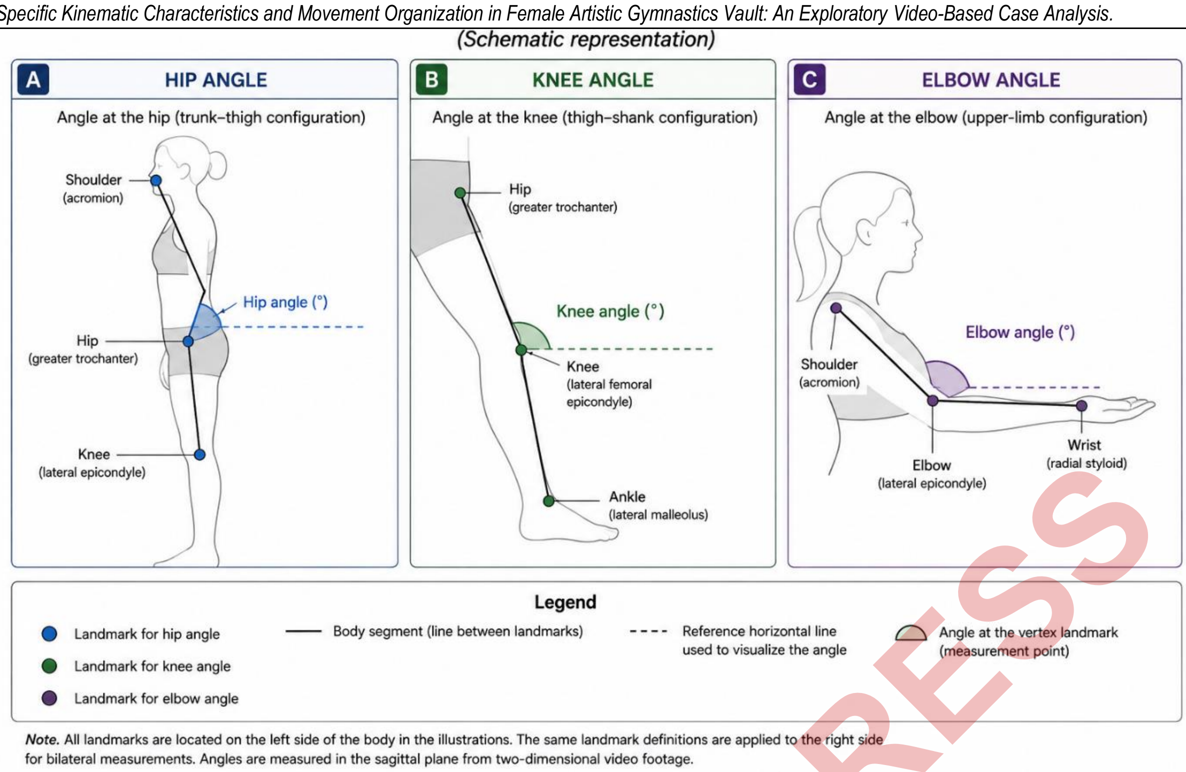

Figure 1. Anatomical landmarks used for two-dimensional joint-angle measurements (Schematic representation).

Figure 1 demonstrates that joint-angle measurements were based on a consistent three-point anatomical landmark configuration rather than subjective visual estimation. The hip angle represents the spatial relationship between the trunk and thigh segments, the knee angle represents the configuration between the thigh and shank, and the elbow angle represents the relationship between the upper arm and forearm. The use of predefined anatomical landmarks provides a standardized reference for frame-by-frame measurement and facilitates consistent application of the measurement procedure across athletes and vault phases.

Because the analysis was conducted from two-dimensional video footage, the measured angles represent projected planar configurations and should therefore be interpreted as two-dimensional kinematic measures rather than complete three-dimensional joint orientations.

Video Technical Specifications

Reliability Analysis

Table 2. Intra-rater reliability of video-based kinematic measurements

Variable	ICC (2,1)	95% CI	SEM	MDC95	Mean Bias	95% LoA	Interpretation
Run-up speed (m/s)	0.99997	0.99856–0.99999	0.0116 m/s	0.0322 m/s	0.0020 m/s	−0.0302 to 0.0342 m/s	Excellent
Hip angle (°)	0.99964	0.99756–0.99976	0.2579°	0.7148°	0.1400°	−0.5748 to 0.8548°	Excellent
Right knee angle – 1st flight (°)	0.99983	0.98288–0.99990	0.1628°	0.4512°	0.0400°	−0.4112 to 0.4912°	Excellent
Left knee angle – 1st flight (°)	0.99877	0.98746–0.99924	0.1910°	0.5296°	−0.0400°	−0.5696 to 0.4896°	Excellent
Hand-contact duration (s)	0.99964	0.99585–0.99977	0.0012 s	0.0032 s	0.0008 s	−0.0024 to 0.0040 s	Excellent
Right elbow angle (°)	0.99719	0.97561–0.99803	0.2802°	0.7766°	0.1200°	−0.6566 to 0.8966°	Excellent
Left elbow angle (°)	0.99953	0.99213–0.99966	0.3557°	0.9859°	0.1400°	−0.8459 to 1.1259°	Excellent
Second-flight elevation (m)	0.99927	0.99153–0.99955	0.0077 m	0.0215 m	0.0020 m	−0.0195 to 0.0235 m	Excellent
Second-flight duration (s)	0.99909	0.99035–0.99945	0.0032 s	0.0088 s	0.0014 s	−0.0074 to 0.0102 s	Excellent
Right knee angle – 2nd flight (°)	0.99845	0.97862–0.99910	0.1936°	0.5368°	0.1000°	−0.4368 to 0.6368°	Excellent
Left knee angle – 2nd flight (°)	0.99909	0.99065–0.99948	0.2419°	0.6704°	0.1200°	−0.5504 to 0.7904°	Excellent

Note. ICC = intraclass correlation coefficient; ICC(2,1) = two-way random-effects, single-measure, absolute-agreement model; CI = confidence interval; SEM = standard error of measurement; MDC95 = minimal detectable change at the 95% confidence level; LoA = limits of agreement. Mean bias represents Measurement 2 − Measurement 1. The reliability analysis was based on five athlete-performance cases measured twice.

Ethical Considerations

Data Transparency and Interpretation

Data Analysis

Analytical Workflow

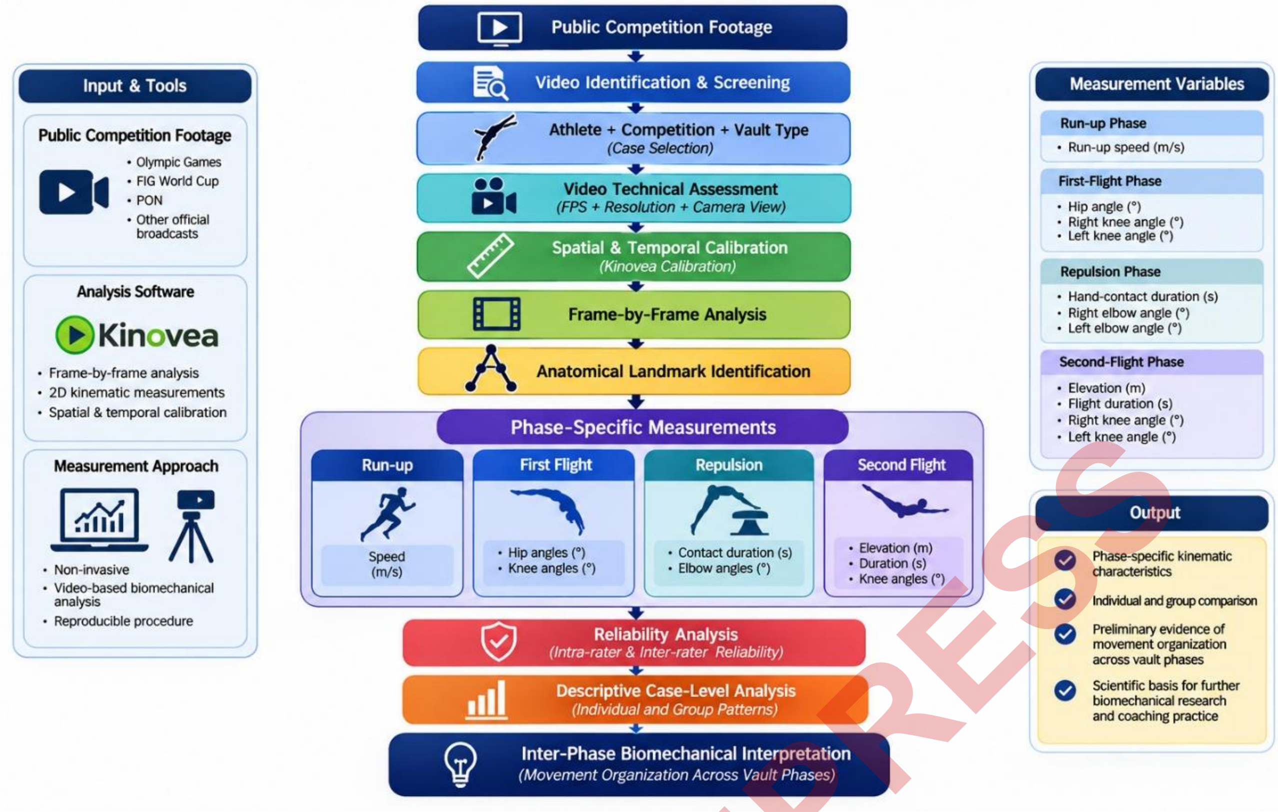

Figure 2. Workflow of the video-based biomechanical analysis of female artistic gymnastics vault performance.

RESULTS

Overview of Phase-Specific Kinematic Characteristics

Run-Up Phase

First-Flight Phase

Repulsion Phase

Second-Flight Phase

Integrated Phase-Specific Pattern

Table 7. Integrated comparison of phase-specific kinematic characteristics

Vault phase	Variable	Olympic/International	National	Pattern with higher mean
Run-up	Speed (m/s)	7.47 ± 2.23	7.95 ± 2.62	National
First flight	Hip angle (°)	162.37 ± 13.86	165.10 ± 16.55	National
First flight	Right knee angle (°)	175.17 ± 1.85	154.75 ± 1.20	Olympic/International
First flight	Left knee angle (°)	174.50 ± 2.01	166.35 ± 2.76	Olympic/International
Repulsion	Contact duration (s)	0.17 ± 0.06	0.15 ± 0.07	Olympic/International
Repulsion	Right elbow angle (°)	172.73 ± 5.23	177.85 ± 2.33	National
Repulsion	Left elbow angle (°)	163.30 ± 17.18	177.65 ± 2.90	National
Second flight	Elevation (m)	2.57 ± 0.21	2.95 ± 0.03	National
Second flight	Duration (s)	0.89 ± 0.10	0.84 ± 0.09	Olympic/International
Second flight	Right knee angle (°)	166.23 ± 1.95	168.35 ± 5.16	National
Second flight	Left knee angle (°)	165.83 ± 4.55	176.75 ± 4.45	National

The integrated results indicate that the two groups did not demonstrate a uniformly higher or lower kinematic profile. Instead, the direction and magnitude of differences depended on the movement phase and variable examined. The Olympic/international-level cases were characterized by more extended first-flight knee positions and slightly longer second-flight duration, whereas the national-level cases demonstrated higher mean run-up velocity and greater measured second-flight elevation.

Descriptive Between-Group Differences

Table 8. Descriptive Between-Group Differences in Phase-Specific Kinematic Variables

Vault Phase	Variable	Olympic/International Mean ± SD	National Mean ± SD	Mean Difference (O/I − N)	Absolute Difference
Run-up	Run-up speed (m/s)	7.47 ± 2.23	7.95 ± 2.62	−0.48 m/s	0.48 m/s
First flight	Hip angle (°)	162.37 ± 13.86	165.10 ± 16.55	−2.73°	2.73°
First flight	Right knee angle (°)	175.17 ± 1.85	154.75 ± 1.20	+20.42°	20.42°
First flight	Left knee angle (°)	174.50 ± 2.01	166.35 ± 2.76	+8.15°	8.15°
Repulsion	Hand-contact duration (s)	0.17 ± 0.06	0.15 ± 0.07	+0.02 s	0.02 s
Repulsion	Right elbow angle (°)	172.73 ± 5.23	177.85 ± 2.33	−5.12°	5.12°
Repulsion	Left elbow angle (°)	163.30 ± 17.18	177.65 ± 2.90	−14.35°	14.35°

Second flight	Elevation (m)	2.57 ± 0.21	2.95 ± 0.03	−0.38 m	0.38 m
Second flight	Flight duration (s)	0.89 ± 0.10	0.84 ± 0.09	+0.05 s	0.05 s
Second flight	Right knee angle (°)	166.23 ± 1.95	168.35 ± 5.16	−2.12°	2.12°
Second flight	Left knee angle (°)	165.83 ± 4.55	176.75 ± 4.45	−10.92°	10.92°

The descriptive comparison showed that the largest angular difference was observed in the right-knee angle during the first-flight phase (20.42°), followed by the left-elbow angle during repulsion (14.35°) and the left-knee angle during the second-flight phase (10.92°). The Olympic/international cases demonstrated higher mean values for the first-flight right- and left-knee angles, whereas the national cases showed higher mean run-up velocity and second-flight elevation. These differences are descriptive and should not be interpreted as evidence of statistically significant population-level differences because only five athlete-level cases were analyzed.

Measurement Reliability

Summary of Results

The results therefore support a phase-integrated interpretation of vault execution. However, the observed relationships should be considered preliminary because the analysis involved only five athlete-level cases and did not directly quantify three-dimensional movement, ground-reaction forces, center-of-mass dynamics, joint moments, or formal inter-phase coordination.

DISCUSSION

Principal Findings and Interpretation

Run-Up Velocity and the Transition Toward Take-Off

First-Flight Joint Configuration

Repulsion and Vaulting-Table Interaction

Second-Flight Elevation, Duration, and Knee Configuration

Inter-Phase Coordination as the Central Biomechanical Pattern

Practical Implications for Coaching

Limitations and Directions for Future Research

CONCLUSION

This study aimed to explore the phase-specific biomechanical characteristics and movement coordination of female artistic gymnasts during vault execution through video-based biomechanical analysis. The findings demonstrate that the observed gymnasts did not exhibit a uniform pattern across all vault phases. National-level cases showed higher mean run-up velocity and second-flight elevation, whereas Olympic/international cases demonstrated greater and more consistent knee extension during the first-flight phase. Differences were also observed in repulsion characteristics and second-flight movement patterns.

Taken together, these findings indicate that vault execution should not be interpreted on the basis of a single kinematic variable. Instead, the results highlight the importance of examining how movement characteristics are organized across successive phases, from the run-up and first flight to repulsion and the second flight. This phase-specific perspective provides preliminary support for considering inter-phase coordination as an important conceptual framework for understanding vault technique, although coordination itself was not directly quantified in the present study.

From a practical perspective, coaches may use phase-specific video feedback to evaluate approach control, first-flight body configuration, table interaction, and second-flight organization as interconnected components of vault execution. Particular attention may be given to the consistency of knee extension during the first-flight phase while avoiding an exclusive focus on maximizing approach speed or flight height.

The findings should be interpreted as exploratory case-level evidence because of the small sample and the use of publicly available video recordings. Future research should therefore examine larger samples using standardized high-speed or three-dimensional motion analysis and incorporate variables such as center-of-mass velocity, joint angular velocity, ground reaction force, impulse, and execution scores. Such research would allow inter-phase coordination to be quantified directly and provide stronger evidence regarding the biomechanical mechanisms underlying successful vault execution.

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Ethical Approval

Consent for Publication

Consent for Publication

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Conflict of Interest

Data Availability

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Generative AI Disclosure

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