IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Kinematic Analysis Of Approach Run And Take-Off In National-Level Female Vaulting Athletes

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Abstract

Vaulting in artistic gymnastics requires optimal coordination of approach velocity, stride mechanics, and take-off posture to maximize performance outcomes. Kinematic variables such as penultimate step stride length (PSSL) and trunk angle at take-off (TATO) are known to influence force transfer, flight height, and rotation efficiency (Hay & Reid, 1982; Takei, 1999; Irwin & Kerwin, 2007). Despite global advances in biomechanical research, limited scientific evidence exists for Indian female vaulting athletes, particularly from regions like Tripura, where access to sports science support is still developing. This study aimed to analyze the relationship between PSSL, TATO, and vaulting performance among national-level female athletes. Twelve national-level female vaulting athletes from Tripura were selected through simple random sampling. A repeated-measures design was used. High-speed video recordings (iPhone 16; 4K/60fps) were captured using a two-camera setup positioned 5 m from the plane of motion. Kinovea software was used to measure PSSL and TATO, with trunk angle determined using anatomical landmarks (greater trochanter and greater tubercle). Pearson Product–Moment Correlation was applied at a 0.05 level of significance to examine relationships between kinematic variables and performance scores. The mean PSSL was 2.34 ± 0.16 m, and mean performance was 9.90 ± 1.25. A moderate positive correlation was found between PSSL and performance ($r = 0.629$, $p = 0.028$). The mean TATO was 105.00° ± 7.79°, with a mean performance of 9.93 ± 1.28. A strong positive correlation was observed between TATO and performance ($r = 0.709$, $p = 0.010$). Both correlations exceeded the critical r-value (±0.576), confirming statistical significance. The findings support existing biomechanical evidence indicating that optimized penultimate stride mechanics enhance take-off positioning and performance (Panoutsakopoulos et al., 2021). Similarly, the strong association between TATO and performance aligns with research highlighting trunk alignment as a determinant of effective force application and flight mechanics during vaulting (Martínez et al., 2017). The results underscore the importance of technical training targeting stride regulation and trunk posture to improve vaulting outcomes. This study contributes valuable region-specific evidence to support performance enhancement and injury prevention among emerging Indian female gymnasts.

Keywords: Artistic gymnastics, Vaulting biomechanics, Penultimate stride length, Kinematic analysis, Female athletes, Performance analysis, Kinovea software

INTRODUCTION

Vaulting in artistic gymnastics demands precise coordination of approach velocity, stride mechanics, and take-off posture, making it one of the most biomechanically complex events in the sport. Research has consistently shown that the approach run and take-off phases strongly influence vault height, rotation, and overall performance quality (Hay & Reid, 1982; Čuk & Karacsony, 2004). Kinematic variables such as stride length, stride frequency, horizontal velocity, and lower-limb joint angles play critical roles in determining the efficiency of force transfer during springboard contact (Takei, 1999; Irwin & Kerwin, 2007). With advances in motion analysis technology, high-speed video and software-based kinematic tools now allow for precise, real-time assessment of these technical elements, improving coaching feedback and injury prevention (Lees, 2002; Atiković, 2012).

Despite the growing scientific focus on gymnastics internationally, biomechanical research on female vaulting athletes in India remains limited. Emerging national-level gymnasts, particularly from regions such as Tripura, often train with restricted access to sports science support, underscoring the need for evidence-based technical evaluation (Bandyopadhyay, 2007; Chakraborty, 2021). In this context, analysing kinematic characteristics specific to Indian female athletes can provide valuable insights for performance optimisation and safer training practices.

This study aims to examine the kinematic parameters of the approach run and take-off in national-level female vaulting athletes, identifying key performance indicators that can inform scientifically grounded coaching interventions and enhance competitive outcomes.

Landing mechanics in artistic gymnastics have received increasing scientific attention due to their strong association with injury risk. A systematic review by **Silva et al. (2023)** highlighted that landings generate high ground reaction forces across all apparatuses, often leading to overuse injuries when poorly executed. Their analysis of 16 studies emphasized the need for more applied, apparatus-specific research to guide coaches in developing safer and more effective landing strategies.

Biomechanical performance in gymnastics skills is also influenced by physical attributes such as explosive strength and flexibility. **Korpová et al. (2023)** demonstrated strong correlations between switch leap height, lower-limb flexibility, and take-off power in junior and senior female gymnasts. Their findings underscore the importance of targeted conditioning to enhance both flexibility and force production for optimum technical execution.

Research on approach mechanics in other sports provides valuable parallels for vaulting. **Hanley et al. (2022)** compared the final approach and take-off phases of male and female world-class pole vaulters, revealing gender-specific differences in step length, approach velocity, and take-off coordination. These insights reinforce the relevance of individualized technical coaching based on biomechanical characteristics.

Similarly, **Panoutsakopoulos et al. (2021)** examined elite female long jumpers and reported that precise regulation of the final steps, along with inter-limb symmetry, is critical for an effective take-off. Their findings highlight the biomechanical importance of stride consistency and joint alignment during the approach phase.

Collectively, these studies emphasize that kinematic control during approach run and take-off is fundamental to performance across various explosive sports. This evidence supports the need for detailed kinematic assessment in gymnastics vaulting, particularly among female athletes, to optimise technique and reduce injury risk.

OBJECTIVES OF THE STUDY:

1. To analyze penultimate step stride length.
2. To analyze trunk angle during take-off.

HYPOTHESIS OF THE STUDY:

Ho, No significant relationship exists between selected kinematic variables, i.e penultimate step stride length and trunk angle during take-off with overall performance.

DELIMITATIONS OF THE STUDY:

1. The study is delimited to national-level female athletes of n=12 from Tripura only, excluding male and beginner gymnasts.
2. It focuses only on the, penultimate step stride length during approach run and trunk angle during take-off.
3. Only kinematic parameters (e.g. joint angles and penultimate step stride length) will be analyzed.
4. Data collection is restricted to one type of vaulting technique (e.g., handspring or Yurchenko) but Handspring, Yamashita, Round-off with or without turn is allowed.

LIMITATIONS OF THE STUDY:

1. Heredity which contributes to both physical and mental efficiency will not be controlled.
2. The study does not analyze physiological or psychological factors affecting performance.
3. Other factors like strength of muscle, speed, flexibility were not taken into consideration while interpreting the results.

SIGNIFICANCE OF THE STUDY:

This study will give valuable insights into vaulting biomechanics, assisting coaches and athletes in refining training methods. The findings can help female gymnasts enhance their performance and lower their chances of becoming injured. Additionally, it will help to improve gymnastics training programs in Tripura, a state noted for producing exceptional gymnasts in India.

METHODOLOGY

Repeated measures Study design group design was followed by the investigator. In this study the investigator measured the penultimate stride length and trunk angle during take-off.

SELECTION OF THE SUBJECTS

To achieve the purpose of these study (N=12) Vaulting Athletes from NSRCC Netaji Subhas Regional Coaching Centre (Tripura Sports Council), Agartala were selected. The subjects were randomly selected among the athletes who represented the National level tournaments.

SELECTION OF THE VARIABLES

Based on the experience gained through review of related literature, books, journals and discussions with experts, the investigator selected variables are analyze penultimate step stride length and analyze trunk angle during take-off.

TEST ADMINISTRATION

The tests were administrated through the Kinovea software. The following variables were

1. To analyze penultimate step stride length.
   Right/Left leg toe OFF to both the leg heel stride
2. To analyze trunk angle during take-off.
   Angle will be measured from Lateral Greater trochanter of femur. Angle will be measured from Greater tubercle of the humerus.

CAMERA PROCEDURE

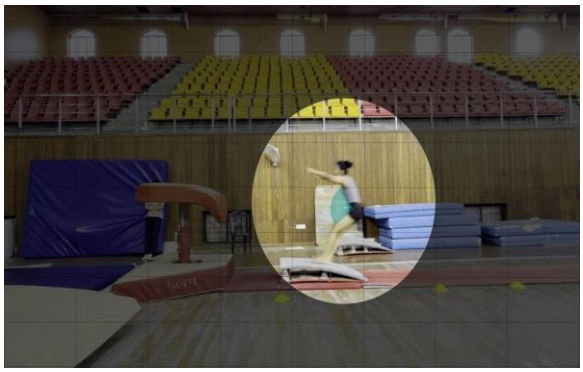
1. It was difficult for the investigator to detect and measure the penultimate stride length and trunk angle during the fast movements using the naked eye.
2. Therefore, high-resolution video analysis was necessary to assess the variables quantitatively and accurately.
3. Two cameras were placed on tripods each positioned 5 meters from the plane of motion and at a height of 1.00 meter to record the movements accurately.
4. The setup was used to capture the penultimate stride step and the trunk angle during take-off.
5. An iPhone 16 was used for video recording, equipped with:
   - A 48MP main camera with advanced image processing.
   - A 12MP ultra-wide lens.
   - Improved low-light performance.
   - 4K video recording capability at up to 60 frames per second (fps).
6. Two tripods supported the cameras to ensure stable and consistent video capture.

STATISTICAL PROCEDURE

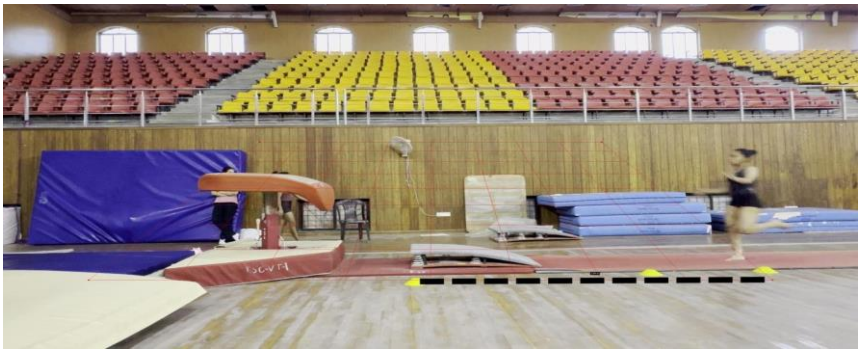
The collected data were analyzed Person correlation for static group design by using the following formula. The obtained data were subjected to statistical treatment using correlation for reliability of the data. In all cases 0.05 level of significance was fixed to test the hypothesis of the study**.**

TESTING PROCEDURE

1. TRUNK ANGLE DURING TAKEOFF



2. PENULTIMATE STEP STRIDE LENGTH



3. Software used for Analyzing: Analysis through Kinovea software version 2023.1.2

IMAGE 1

IMAGE 1 SHOWS THE CALIBRATION OF VIDEO ANALYSIS.

IMAGE-2

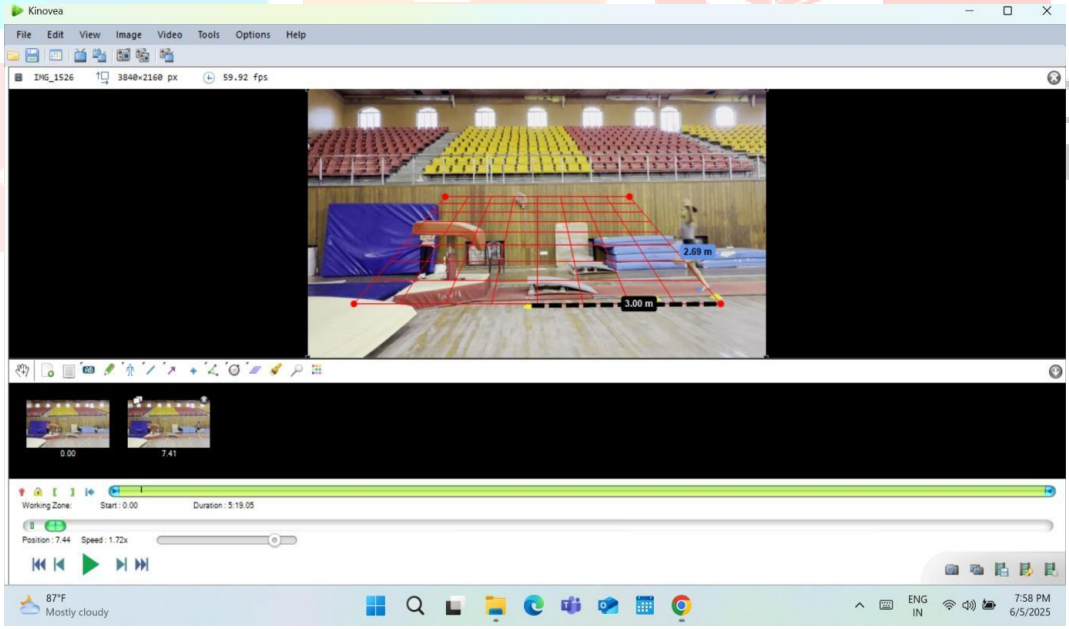


IMAGE 2 SHOWS THE PENULTIMATE STEP STRIDE LENGTH VIDEO ANALYSIS.

RESULTS AND DISCUSSIONS

TABLE I

Table I shows the mean, standard deviation and obtained correlation value of Gymnast penultimate step length among National female vaulters in Gymnastics.

DESCRIPTIVE STATISTICS			
	Mean	**Std. Deviation**	**N**
PSSL	**2.3442**	**.15617**	**12**
Performance	**9.9000**	**1.25481**	**12**

The results presented in the table showed the descriptive statistics of Penultimate Step Stride Length (PSSL) and performance among national-level female gymnasts specializing in vaulting from Tripura. The mean PSSL was 2.34 meters with a standard deviation of 0.16, while the mean performance score was 9.90 with a standard deviation of 1.25, based on data collected from 12 athletes.

TABLE II

Table II shows Pearson Product-Moment Correlation between Penultimate Step Stride Length and Performance.

CORRELATIONS			
		PSSL	**Performance**
PSSL	**Pearson Correlation**	**1**	**.629***
	Sig. (2-tailed)		**.028**
	N	**12**	**12**
Performance	**Pearson Correlation**	**.629***	**1**
	Sig. (2-tailed)	**.028**	
	N	**12**	**12**

*. Correlation is significant at the 0.05 level (2-tailed).

The Pearson Product-Moment Correlation was conducted to examine the relationship between PSSL and Performance. The analysis revealed a correlation coefficient of r = 0.629, indicating a moderate positive linear relationship between the two variables. This suggests that as PSSL scores increase, Performance scores also tend to increase. The correlation was found to be statistically significant at the 0.05 level, with a p- value of 0.028 (2-tailed). Given the sample size of N = 12, the critical value for significance at the 0.05 level is ±0.576. Since the observed correlation coefficient (0.629) exceeds this critical value, it confirms the significance of the relationship.

FIGURE I

Figure 1 shows Graphical presentation of Penultimate step stride length and performance point

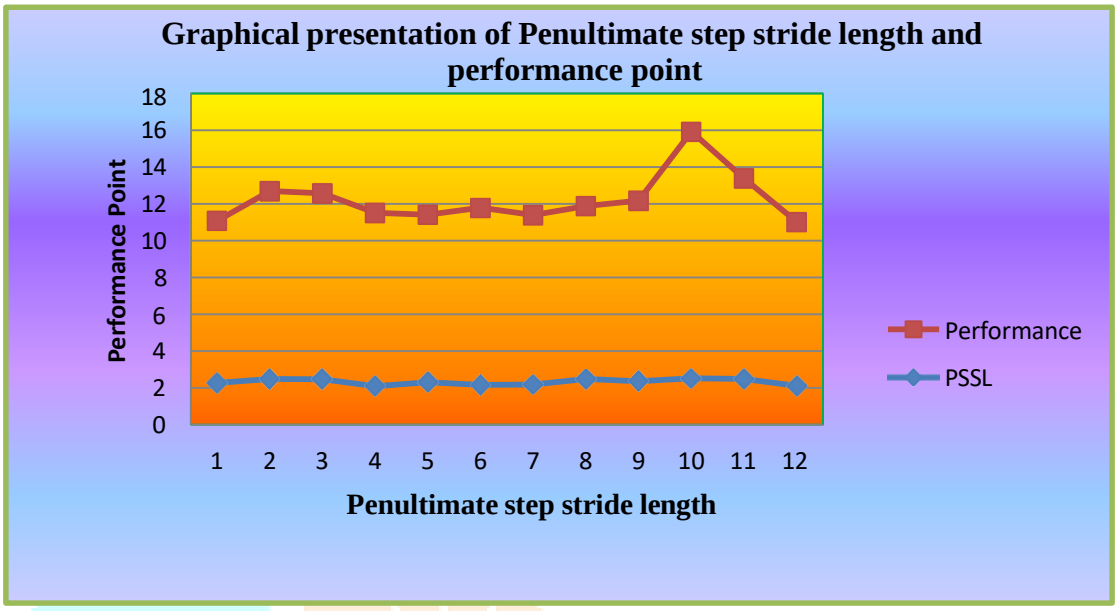


Figure 1 shows The Graphical presentation how the Penultimate Step Stride Length (PSSL) of 12 national-level female gymnasts from Tripura affects their performance points. PSSL stays pretty much the same, however performance scores change from person to person. The picture implies that there is a positive link between PSSL and performance, which backs up the statistical results.

TABLE III

Table iii shows the mean, standard deviation and obtained correlation value of gymnast trunk angle during takeoff among national female vaulters in gymnastic.

Descriptive Statistics			
	Mean	**Std. Deviation**	**N**
TATO	**105.0000**	**7.78915**	**12**
Performance	**9.9250**	**1.27929**	**12**

The descriptive statistics revealed that the mean Take-Off Angle at Take-Off (TATO) was 105.00 degrees with a standard deviation of 7.79, while the mean performance score was 9.93 with a standard deviation of 1.28, based on data from 12 national-level female gymnasts.

TABLE IV

Table IV shows Pearson Product-Moment Correlation between Trunk Angle during Take-off and Performance.

CORRELATIONS		TATO	Performance
TATO	Pearson Correlation	1	.709**
	Sig. (2-tailed)		.010
	N	12	12
Performance	Pearson Correlation	.709**	1
	Sig. (2-tailed)	.010	
	N	12	12

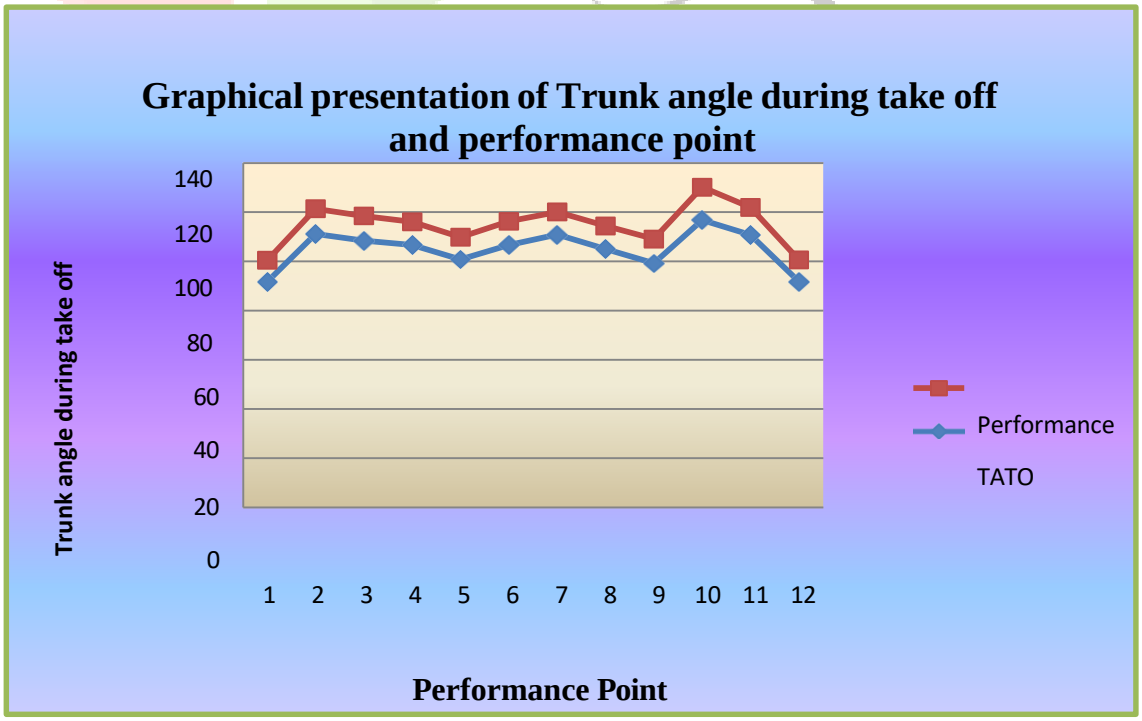
**. Correlation is significant at the 0.01 level (2-tailed).

The Pearson Product-Moment Correlation was used to examine the relationship between TATO and Performance. The analysis yielded a correlation coefficient of r = 0.709, indicating a strong positive linear relationship between the two variables. This means that as TATO values increase, Performance scores also tend to increase. The

significance level (2-tailed) was found to be p = 0.010, which is below the 0.01 threshold, indicating that the correlation is statistically significant at the 1% level. Considering the sample size of N = 12, the critical value for significance at the 0.05 level is ±0.576. Since the obtained correlation coefficient (0.709) is greater than this critical value, it confirms the significance and strength of the relationship.

FIGURE II

Line diagram showing the trunk angle during takeoff and the performance point of national female vaulters in gymnastic



The graph illustrates the relationship between Trunk Angle During Take-Off (TATO) and performance scores of 12 national-level female gymnasts from Tripura. The mean TATO was 105.00 degrees with a standard deviation of 7.79, while the mean performance score was 9.93 with a standard deviation of 1.28. The plotted data indicate a parallel trend between trunk angle and performance, suggesting a possible positive association between the two variables.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The results of the present study, which identified a moderate positive correlation between Penultimate Stride Length (PSSL) and performance ($r = 0.629$, $p = 0.028$), align closely with the findings of **Panoutsakopoulos et al. (2021)**. Their research on elite female long jumpers emphasized the importance of controlling the penultimate stride to optimize body positioning for take-off. Similarly, in the context of vaulting, the current findings suggest that gymnasts with a more efficient and controlled penultimate stride are better able to establish the biomechanical conditions necessary for successful vault execution.

Furthermore, the strong positive correlation observed between Trunk Angle at Take-Off (TATO) and performance ($r = 0.709$, $p = 0.010$) is consistent with the conclusions of **Martínez et al. (2017)**, who highlighted the critical role of trunk posture and joint alignment in vaulting performance. Their study demonstrated that optimal trunk angles enable more effective force application and improved flight mechanics. In this study, gymnasts who maintained better trunk alignment during take-off achieved higher performance scores, underscoring the biomechanical advantage of proper body positioning. Thus, the present findings reinforce the biomechanical principles identified in earlier research, confirming that both penultimate stride control and trunk alignment are key determinants of performance in vaulting.

CONCLUSIONS

The present study investigated the relationship between Penultimate Stride Length (PSSL), Trunk Angle at Take-Off (TATO), and vaulting performance among 12 national- level female gymnasts from Tripura. The results revealed a statistically significant moderate positive correlation between PSSL and performance, as well as a strong positive correlation between TATO and performance. These findings indicate that both the penultimate stride and trunk posture during take-off play a critical role in influencing performance outcomes in vaulting.

The outcomes are supported by prior studies, such as Panoutsakopoulos et al. (2021), which emphasized the importance of stride adjustment for optimal take-off positioning, and Martínez et al. (2017), which highlighted the role of trunk alignment and joint angles in enhancing flight efficiency. Therefore, coaches and athletes should prioritize technical training that emphasizes precise stride control and optimal trunk posture during take-off to improve performance in gymnastics vaulting.

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