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Comparative Analysis of Selected Linear Kinematic Variables among National and International Race Walkers

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ABSTRACT

The purpose of the present study was to compare selected linear kinematic variables between national and international race walkers participating in 20 km race walking events. A total of 20 male race walkers were selected as subjects for the study, comprising national-level and international-level athletes. Only those athletes who had participated at national and international competitions and were free from injuries or muscular disorders were included in the study. The selected variables were stride length, cadence, average speed, stance duration, and symmetry index. Data were collected using a G-sensor, which was positioned at the lumbosacral region corresponding to the S1–S2 vertebrae to ensure accurate and reliable gait assessment. Descriptive statistics were used to develop the descriptive profile of the variables, while the Shapiro-Wilk test was applied to examine the normality of data. Since the data were normally distributed, an independent t-test was used to compare the selected linear kinematic variables between national and international race walkers. The level of significance was set at 0.05, and statistical analysis was performed using IBM SPSS Statistics. The results revealed significant differences in all selected variables. International race walkers demonstrated significantly greater stride length, higher cadence, faster average speed, lower stance duration, and better symmetry index compared to national race walkers. These findings indicate that international-level athletes possess superior biomechanical efficiency, technical control, and movement coordination, which contribute to enhanced race walking performance. The study concludes that biomechanical optimization plays a crucial role in achieving higher competitive standards in race walking. Coaches and sports scientists should therefore focus on objective biomechanical assessment and technique refinement to improve athlete performance.

Introduction

Race walking is a highly specialized discipline of athletics that requires athletes to move at maximum possible speed while complying with strict technical rules established by World Athletics. According to competition regulations, athletes must maintain continuous contact with the ground, and the advancing leg must remain straight from the point of initial contact until it passes beneath the body. These technical demands distinguish race walking from normal walking and running and make biomechanical efficiency a primary determinant of success. Unlike running events where flight phase contributes to speed generation, race walking performance depends upon optimizing gait mechanics within legal movement constraints. This requires exceptional neuromuscular coordination, postural control, and movement economy (Hanley, 2011; Pavei & La Torre, 2016; Gómez-Ezeiza et al., 2019; World Athletics, 2009).

Performance in race walking is strongly influenced by linear kinematic variables such as stride length, cadence, average speed, stance duration, and symmetry index. These variables determine the effectiveness of forward propulsion and influence the athlete's ability to sustain speed over long distances without technical faults. Efficient race walkers minimize vertical displacement and braking forces while maximizing horizontal displacement and movement economy. According to Hanley, Bissas, and Drake (2011), successful athletes maintain an optimal interaction between stride length and cadence rather than relying excessively on one parameter alone. Similarly, Pavei et al. (2014) emphasized that step frequency and contact characteristics are key contributors to elite performance, particularly during the final stages of competition when fatigue affects technique. Recent reviews have confirmed that spatiotemporal gait variables remain among the most reliable indicators of technical proficiency and competitive success (Pharswan & Singh, 2024; Jurlin & Babić, 2023).

Stride length is one of the most influential determinants of race walking performance because it directly contributes to horizontal velocity. A longer and technically efficient stride enables athletes to cover greater distance per step without violating race walking regulations. Efficient pelvic rotation, controlled hip extension, and appropriate foot placement are essential for achieving optimal stride length. However, excessive stride length may result in overstriding, increased braking forces, higher metabolic cost, and greater risk of visible loss of contact. Hanley et al. (2011) reported that elite performers achieved superior results through optimized rather than maximized stride length. Similarly, Gómez-Ezeiza et al. (2019) found that stride characteristics were closely associated with competitive level and fatigue resistance during endurance events. The biomechanical reports of World Athletics also suggest that elite race walkers maintain stride lengths approaching approximately 70% of body height while preserving legality (World Athletics, 2009; Pharswan & Singh, 2024).

Cadence, defined as the number of steps taken per minute, is another critical determinant of race walking speed. Since speed is mathematically the product of stride length and cadence, both parameters must work in coordination. International-level athletes often demonstrate better cadence control due to advanced technical preparation and greater neuromuscular adaptation. Higher cadence allows athletes to sustain velocity without excessive overstriding, thereby reducing braking forces and improving movement efficiency. Jurlin and Babić (2023) reported that race walking biomechanics were significantly influenced by coaching and technical refinement, particularly in cadence-related adjustments among better-performing athletes. Tucker and Hanley (2020) also observed that increases in walking speed were associated with changes in step frequency while maintaining gait stability and symmetry. These findings indicate that cadence is not merely a temporal variable but an important marker of technical expertise and competitive readiness (Pavei et al., 2014; Gómez-Ezeiza et al., 2019).

Average speed is the ultimate indicator of race walking performance and reflects the combined influence of biomechanical, physiological, and technical factors. Unlike sprinting, where explosive force dominates performance, the 20 km race walk requires athletes to sustain high submaximal speed over prolonged durations while preserving technique and avoiding penalties. Even minor improvements in stride mechanics or contact efficiency can lead to significant performance advantages across the full race distance. Pavei and La Torre (2016) reported that race walking performance is strongly associated with efficiency of movement and fatigue resistance, particularly during the later phases of competition. Hanley (2011) similarly found that elite athletes who maintained greater average speed showed better consistency in gait variables throughout the race. Studies on endurance gait patterns have further shown that optimized spatiotemporal characteristics contribute significantly to reduced metabolic demand and sustained competitive speed (Jordan et al., 2017; Pharswan & Singh, 2024).

Stance duration, which refers to the time the foot remains in contact with the ground, is particularly important in race walking because continuous contact is mandatory. Unlike running, where a flight phase is expected, race walkers must carefully regulate contact time to maintain legality while achieving competitive speed. Excessive stance duration may reduce propulsion and efficiency, whereas insufficient contact time increases the risk of disqualification due to visible loss of contact. Therefore, stance duration must be optimized rather than minimized. Pavei et al. (2014) observed that elite race walkers displayed shorter but controlled contact phases, enabling efficient propulsion without technical faults. Tucker and Hanley (2020) also suggested that contact-time variables should be carefully monitored because they are directly related to officiating decisions and competitive outcomes. Recent wearable sensor studies further support the importance of stance duration as an indicator of gait legality and performance quality (Taborri et al., 2023; Rotstein et al., 2021).

Symmetry index has emerged as an important parameter in gait analysis because it reflects bilateral coordination and movement efficiency. Gait symmetry indicates how equally both limbs contribute to locomotion and is strongly associated with performance quality, injury prevention, and movement economy. In race walking, asymmetrical gait patterns may lead to uneven loading, greater fatigue, and reduced technical efficiency. Bergamini, Cereatti, and Pavei (2024) emphasized that gait symmetry is one of the most informative descriptors of locomotion quality and that symmetry values vary according to walking speed and measurement method. Rotstein et al. (2021) also reported that lower-limb asymmetry influences performance consistency and injury susceptibility in endurance athletes. Stable symmetry is therefore considered an indicator of superior technical control and long-term performance sustainability. International-level athletes are generally expected to demonstrate better symmetry due to greater technical training exposure and competitive experience (Tucker & Hanley, 2020; Pharswan & Singh, 2024).

The advancement of wearable sensor technology has significantly improved biomechanical assessment in sports science. Traditional motion analysis systems such as force plates, multi-camera motion capture systems, and instrumented treadmills are expensive, laboratory-dependent, and difficult to use in real training environments. In contrast, wearable inertial measurement units such as G-sensors provide portable, reliable, and repeatable measurement of gait variables under field conditions. These devices are especially useful in race walking because they allow practical assessment of cadence, stance duration, symmetry, and movement faults without disturbing natural performance patterns. Taborri et al. (2023) demonstrated that wearable inertial sensors integrated with machine learning algorithms successfully identified race walking faults with high accuracy, supporting their use in performance monitoring and officiating assistance. Similarly, Bergamini et al. (2024) highlighted the importance of wearable technology in evaluating gait symmetry and movement quality during real-world locomotion.

Although several studies have investigated elite race walking biomechanics, most research has focused on world-class athletes during international championships or laboratory-based analysis of general gait mechanics. Very limited studies have directly compared selected linear kinematic variables between national-level and international-level race walkers using wearable sensor-based field assessment. Most previous investigations have concentrated mainly on stride length and cadence, whereas stance duration and symmetry index have received comparatively less attention despite their importance in technical legality and movement efficiency (Hanley, 2011; Taborri et al., 2023; Bergamini et al., 2024; Jurlin & Babić, 2023). Furthermore, in the Indian context, there is a lack of biomechanical comparison studies involving race walkers of different competitive standards.

Coaches and sports scientists in India often depend more on observational analysis than on objective biomechanical assessment for technique correction and performance enhancement. This limits evidence-based coaching, particularly for athletes progressing from national to international levels. Identifying the specific biomechanical differences between these two groups can provide valuable scientific guidance for training prescription, technical refinement, and talent identification. Therefore, there is a clear need to conduct a comparative investigation of selected linear kinematic variables among national and international race walkers. Hence, the present study was undertaken to compare stride length, cadence, average speed, stance duration, and symmetry index among national and international race walkers participating in 20 km events.

Methodology

Selection of Subjects

For the purpose of the study, a total of 20 race walkers specializing in the 20 km race walking event were selected as subjects and were categorized into two groups based on their competitive level, namely national-level and international-level race walkers. Only those athletes who had participated in recognized national and international competitions were considered for inclusion in the study. Furthermore, to ensure the accuracy and reliability of the results, only those race walkers who were free from any injuries, muscular disorders, or physical limitations that could affect their performance were included as subjects.

Variables

The following selected linear kinematic variables were chosen for the study:

- Stride Length
- Cadence
- Average Speed
- Stance Duration
- Symmetry Index

These variables were selected due to their direct relevance to race walking performance and biomechanical efficiency.

Instrumentation

The data were collected using a G-sensor, a wearable motion analysis device used for gait and movement assessment. To obtain reliable and repeatable data during the execution of the tests, proper positioning of the sensor was ensured. For the Walking Test protocol, the sensor was positioned below the line connecting the two dimples of Venus at the lumbosacral passage, corresponding to the S1–S2 vertebrae. The sensor was inserted inside the belt with the flat part facing towards the back of the pocket and centered on the identified point of the spinal column. The belt was firmly tightened to provide adequate support and to prevent movement during the execution of the test.

Statistical Procedure

For analyzing the data of the study, descriptive statistics were used to develop the descriptive profile of the subjects and variables. An Independent t-test was employed to compare the selected biomechanical parameters between national and international race walkers. The level of significance was set at 0.05. All statistical analyses were carried out using IBM SPSS Statistics software.

Results

The purpose of the study was to compare selected linear kinematic variables between national and international race walkers participating in 20 km race walking events. The variables selected for the study were stride length, cadence, average speed, stance duration, and symmetry index. Shapiro-Wilk test used to examine the normality of data distribution for all selected variables. Since all p-values were greater than the level of significance set at 0.05, it was concluded that the data for all selected variables were normally distributed. Therefore, the use of parametric statistics, particularly the independent t-test, was considered appropriate for comparing the two groups.

Table 01. Descriptive Statistics

Variable	National		International	
	Mean	Standard Deviation	Mean	Standard Deviation
Stride Length	1.135	0.0333	1.285	0.026
Cadence	197.870	2.594	221.166	2.350
Average Speed	3.756	0.128	4.731	0.096
Stance Duration	.334	0.008	.290	0.012
Symmetry Index	93.250	0.623	97.474	0.864

Table 02. Independent t-test

Variable	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Stride Length	-11.158	18	.000	-0.1504	0.0134
Cadence	-21.046	18	.000	-23.2960	1.1068
Average Speed	-19.232	18	.000	-0.9744	0.0506
Stance Duration	9.398	18	.000	0.0432	0.0045
Symmetry Index	-12.531	18	.000	-4.2240	0.3370

Table 02 presents the results of the independent t-test conducted to compare selected linear kinematic variables between national and international race walkers.

Since all calculated p-values were less than 0.05, it was concluded that significant differences existed between national and international race walkers in all selected linear kinematic variables. International race walkers showed superior performance in stride length, cadence, average speed, and symmetry index, while national race walkers showed higher stance duration.

These findings suggest that higher-level race walkers possess better biomechanical efficiency, technical control, and movement coordination, which contribute to improved race walking performance.

Discussion

The present study was conducted to compare selected linear kinematic variables—stride length, cadence, average speed, stance duration, and symmetry index—between national and international race walkers participating in 20 km race walking events. The findings revealed significant differences between the two groups in all selected variables. International race walkers demonstrated superior stride length, cadence, average speed, and symmetry index, whereas national race walkers showed significantly greater stance duration. These findings indicate that higher competitive level is associated with better biomechanical efficiency, technical control, and movement coordination, which are essential for successful race walking performance.

The results of the present study showed that international race walkers had significantly greater stride length than national race walkers. This finding is consistent with the observations of Hanley, Bissas, and Drake (2011), who reported that elite race walkers maintained longer and more efficient strides, allowing greater horizontal displacement without violating technical rules. Similarly, Pavei et al. (2014) stated that stride length is one of the strongest predictors of race walking speed because it directly influences forward progression and competitive performance. Gómez-Ezeiza et al. (2019) also found that higher-level endurance athletes demonstrate superior stride characteristics due to better pelvic mobility, hip extension, and neuromuscular coordination. The greater stride length observed among international race walkers in the present study may therefore be attributed to superior technical refinement and training adaptation developed through exposure to high-level competition.

Cadence was also found to be significantly higher among international race walkers compared to national race walkers. Since race walking speed is the product of stride length and cadence, improvements in both variables are essential for performance enhancement. Tucker and Hanley (2020) reported that elite race walkers increased speed primarily through optimized step frequency while maintaining technical stability. Similarly, Jurlin and Babić (2023) concluded that cadence-related adjustments are strongly influenced by technical coaching and are characteristic of better-performing race walkers. Pavei and La Torre (2016) also emphasized that elite athletes maintain higher cadence without excessive energy expenditure because of better neuromuscular efficiency. The present finding supports the view that international athletes possess more effective stride-cadence coordination, which contributes significantly to competitive success.

A significant difference was also observed in average speed, with international race walkers demonstrating higher mean values than national race walkers. This finding is expected because average speed is the ultimate expression of technical, physiological, and biomechanical efficiency in race walking. Hanley (2011) reported that elite race walkers who maintained greater average speed also showed superior consistency in gait variables throughout competition. Jordan, Challis, and Newell (2017) found that optimized spatiotemporal characteristics improve locomotor economy and reduce fatigue-related decline in performance. Similarly, Pavei and La Torre (2016) observed that performance level is strongly associated with the ability to sustain technically efficient speed over prolonged distances. Therefore, the significantly greater average speed of international race walkers in the present study reflects their better movement economy and competitive readiness.

The findings further revealed that national race walkers had significantly greater stance duration compared to international race walkers. Since race walking requires continuous ground contact, stance duration is a crucial indicator of technical legality and gait efficiency. However, excessively prolonged contact time may reduce propulsion and compromise performance. Pavei et al. (2014) observed that elite race walkers exhibit shorter but well-controlled contact phases, allowing efficient force transfer without visible loss of contact. Tucker and Hanley (2020) similarly suggested that reduced but technically safe contact time is associated with better competitive performance. Taborri et al. (2023) also demonstrated that wearable inertial sensors can accurately detect race walking faults related to contact time and gait transitions. The lower stance duration observed among international race walkers in the present study indicates superior technical proficiency and better control of legal movement patterns.

Symmetry index was significantly higher among international race walkers, indicating better bilateral coordination and movement efficiency. Gait symmetry is an important indicator of locomotor quality because symmetrical movement reduces unnecessary muscular compensation, lowers injury risk, and improves performance sustainability. Bergamini, Cereatti, and Pavei (2024) emphasized that gait symmetry is one of the most informative descriptors of walking quality and is closely associated with speed and movement control. Rotstein et al. (2021) also reported that lower-limb symmetry is strongly related to performance consistency and reduced biomechanical stress among endurance athletes. Tucker and Hanley (2020) found that elite race walkers maintained stable symmetry even at increased speeds, reflecting advanced neuromuscular coordination. Therefore, the higher symmetry index observed among international race walkers in the present study may be explained by their superior technical training and long-term competitive exposure.

The findings of the present investigation also support the growing importance of wearable sensor technology in biomechanical assessment. The use of G-sensor allowed accurate measurement of stride length, cadence, stance duration, and symmetry index under practical field conditions. Traditional laboratory-based motion analysis systems are often expensive and difficult to use during natural training sessions, whereas wearable sensors provide real-time and ecologically valid performance analysis. Taborri et al. (2023) strongly recommended wearable inertial sensors for race walking evaluation because of their reliability in detecting movement faults and technical inefficiencies. Similarly, Bergamini et al. (2024) highlighted that wearable technology provides valuable insight into gait symmetry and locomotor quality in sports performance monitoring. The present study demonstrates that such technology can be effectively used for comparing athletes of different competitive standards and supporting evidence-based coaching.

Overall, the findings of this study clearly indicate that international race walkers possess superior biomechanical characteristics compared to national race walkers. Better stride length, higher cadence, greater average speed, lower stance duration, and improved symmetry reflect more efficient technique and greater movement economy. These findings are in agreement with previous literature and confirm that biomechanical optimization plays a major role in race walking success. Coaches and sports scientists should therefore emphasize objective biomechanical assessment and technical correction during training, particularly for athletes progressing from national to international competition. The present study provides valuable scientific evidence for performance enhancement and talent development in competitive race walking.

Conclusion

The present investigation revealed statistically significant intergroup differences between national- and international-level race walkers across all selected linear kinematic parameters, including stride length, stride frequency, mean locomotion velocity, stance phase duration, and symmetry index. International-level athletes exhibited superior biomechanical profiles characterized by greater stride length, elevated stride frequency, higher mean velocity, abbreviated stance phase duration, and enhanced bilateral gait symmetry. These outcomes indicate that elite performance in race walking is strongly correlated with optimized biomechanical efficiency, neuromuscular coordination, and precise technical execution. Reduced stance phase duration and improved gait symmetry further reflect greater compliance with race walking legality criteria and diminished propensity for technical infractions. IMU-based G-sensor technology was validated as a reliable instrument for field-based kinematic assessment. It is recommended that coaches and sports scientists integrate objective kinematic monitoring and systematic technique intervention within training paradigms to facilitate the advancement of national-level athletes toward internationally competitive biomechanical benchmarks.

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