

The effect of velocity on flight phase duration in race walking: a comparative study of three cases

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Published online: July 31, 2023

(Accepted for publication July 15, 2023)

DOI:10.7752/jpes.2023.07221

Abstract:

The conventional race walking technique adheres to competition rules by excluding a noticeable flight phase visible to the human eye. However, race walkers often exhibit a slight flight phase, sparking an ongoing debate: Is the flight phase permissible? Is it acceptable if the referee fails to detect it? Is the flight phase an inherent part of the race walking technique that cannot be eliminated? The objective of this study was to examine the characteristics of the flight phase in race walking at different speeds. Additionally, the study aimed to compare the performance of individuals in the 20-km distance with the average TOP10 male results from three Olympic games, as well as Y. Suzuki's world record. All participants completed three race walking trials on a level treadmill, with the trials conducted in a randomized order. The walking kinematics were observed using the Optojump Next optical system. Our study revealed that race walkers were able to maintain flight time duration below the threshold of 0.04 s, which is the upper limit undetectable by the human eye, at their competition velocity. However, the impact on flight time varied at higher velocities. Double support steps were rare, occurring less than 2% of the time during race walking at competition velocity. Our findings highlight the importance of keeping the flight phase within specified threshold levels to ensure compliance with competition rules. Further research and potential implementation of electronic control systems may enforce these rules and provide valuable insights for athletes, coaches, and spectators.

Keywords: athletics, gait, race walking, kinematics, flight phase

Introduction

Achieving success in competitive race walking necessitates a combination of high endurance and exceptional technical abilities (Gomez-Ezeiza et al. 2018). While endurance plays a vital role in various endurance sports, race walking possesses distinctive biomechanical features that distinguish it from others (Dona et al., 2009). The technique employed in race walking must adhere to both biomechanical efficiency (Etxebarria et al., 2022) and competition regulations (Hanley, Bissas, & Drake, 2011). A fundamental biomechanical characteristic of race walking lies within its walking cycle, specifically the flight phase, as defined and outlined in rule 230.1 of the International Association of Athletics Federations (IAAF, 2017). This rule states, "Race walking is a sequence of steps where the walker maintains contact with the ground, ensuring an imperceptible loss of contact visible to the human eye."

Previous studies have established that flight times below 0.04 seconds elude detection by judges (Knicker & Loch, 1990; De Angelis & Menchinelli, 1992), suggesting that a brief flight phase could be a natural component of the race walking cycle. This observation underscores the necessity for flexibility when investigating the kinematics of race walking, as the duration of the flight phase can vary. Researchers have the option to define a flight phase irrespective of its duration or establish a threshold to exclusively record flight phases surpassing a specific duration (Caporaso & Grazioso, 2020). Sport biomechanics research methods offer accurate measurements of flight phase durations, regardless of their visibility to the human eye, within each walking cycle.

The walking cycle is commonly divided into two primary phases: the stance phase and the swing phase. The stance phase encompasses the duration from heel contact to toe-off, while the swing phase spans from toe-off to heel contact. Each walking step commences with one foot's heel making contact with the ground and concludes when the other foot's heel establishes contact. Within the stance phase, there exist additional subdivisions referred to as the braking and propulsive phases. The braking phase occurs when the foot is positioned in front of the body's center of mass, whereas the propulsive phase transpires when the foot is behind the center of mass during walking, resulting in acceleration (Preatoni et al., 2006). The duration of the stance phase, commonly known as contact time or support time (Koji et al., 2020), represents a crucial parameter within the walking cycle.

Step time, including contact time and flight time, exhibits an inverse relationship with cadence or step rate. In race walking, elevated velocities correlate with reduced step times and heightened cadences (Cairns et al.,

1986). The relatively brief duration of the flight phase in race walking contributes to the attainment of shorter step times, primarily due to the typically abbreviated contact times observed in this style of walking.

Step frequency, also referred to as cadence, represents the quantity of steps executed within a given time interval and can be measured in steps per second or steps per minute. Similar to running, the speed at which race walking occurs is determined by the combination of step length and frequency (Hoga et al., 2003). Race walkers employ various strategies to maintain a balanced walking velocity while managing the presence of the flight phase. Men are walking faster than women because of longer steps but no difference in step frequency was determined. A reduction in step length caused velocity loss in a 20 km race walking (Hanley et al., 2011). Significant correlation has been found between step length and walking velocity (Amara & Mkaouer, 2020; Pavei & Torre, 2016).

Step length is influenced by several factors, including shoe length (as race walkers achieve full contact with the ground using the entire foot), the distance covered during the flight phase, and the distance between the body's center of mass and the foot at initial contact and toe-off (Hanley, Bissas, & Drake, 2011; Lafortune et al., 1989). Certain studies propose that reducing step length could potentially result in significant velocity loss during competition, prompting race walkers to make minimal adjustments to the flight phase in order to sustain their velocity during races (Knicker & Loch, 1990).

Research conducted by Hanley, Bissas, and Drake (2013) has revealed a correlation between the flight phase in race walking and changes in velocity. In race walking, there exists the option of either a flight time or a double support phase, during which both feet remain in contact with the ground. The double support phase occurs across two consecutive stance phases, partially overlapping with each other, within a single gait cycle. Likewise, the flight phase can be described as a component of both the ongoing and subsequent swing phase. Prior studies have indicated that the flight phase transpires more frequently than the double support phase. As the flight phase is part of the swing phase, it results in an uneven swing-to-stance ratio, with more time allocated to swing than stance. In theory, these durations should be equal if the walking velocity remains constant. However, the inclusion of both double support and flight times contributes to a deviation from the expected 50:50 proportion in the swing-to-stance ratio (Hanley & Bissas, 2013).

Race walkers demonstrate remarkable endurance by covering impressive distances of up to 35 km in competitions (previously up to 50 km), putting forth tremendous efforts. However, their performance may come to an abrupt halt at any moment if the rules are not adhered to. Therefore, conducting comprehensive studies on race walking biomechanics becomes crucial in assisting athletes, coaches, and judges in applying and synchronizing their knowledge during practical competition scenarios. This holds true even for shorter distances, as even slight technical errors, or deviations from the competition rules during the flight phase can significantly impact race performance. With the upcoming Olympic Games, where race walkers may participate in both longer distances, such as 20 km, and shorter distances, where two athletes alternate walking a 10-kilometer distance twice, it becomes essential to comprehend how race walking biomechanics can influence athletes' performance and adherence to competition rules.

Our hypothesis postulates that when race walkers are performing at their individual race pace, the average duration of the flight phase for most strides will typically fall below 0.04 seconds. However, we anticipate that when walking at the velocity achieved by the world's top athletes, the duration of the flight phase will surpass this threshold.

Material & methods

Participants

The study included three male race walkers who possess experience competing at both national and international levels. Table 1 offers a comprehensive overview of their age, anthropometric measurements, and pertinent competitive characteristics.

Table 1. Descriptive characteristics of participants

Participant	Age (years)	Training experience (years)	Height (cm)	PB in 20 km distance
RW1	22	15	181	1:26:15
RW2	25	16	185	1:30:33
RW3	24	18	175	1:27:01

Procedure

All participants successfully completed four distinct walking trials on a motorized treadmill, with each trial lasting a duration of 2 minutes. The trials were meticulously carried out at varying velocities, precisely detailed in Table 2.

Table 2. Velocity in the race walking trials

Walking trial	Velocity	Description
1st	13.3 km/h	The average velocity of RW2's season's best (SB) performance in the 20 km
2nd	14.0 km/h	The average velocity of RW1 and RW3 season's best (SB) performance in the 20 km
3rd	15.0 km/h	The average race walking velocity for the top 10 male results in the 20 km event, with a time of 1:19:58, from the Olympic Games in Beijing, London, and Rio de Janeiro
4th	15.7 km/h	The average velocity of Y. Suzuki's world record in the 20 km distance, with a time of 1:16:36, set in 2015

Each trial was conducted as an independent event during the off-season, with a one-week interval separating each trial. The order of the trials was randomized for every participant to minimize any potential order effects. All athletes wore identical attire and racing shoes for consistency across all trials. Before each trial, participants engaged in a warm-up procedure designed to closely mimic their typical pre-race routine. This warm-up routine encompassed elements such as slow walking and running, stretching exercises, and brief bursts of speed to adapt to the velocity of the upcoming trial.

All participants were well-acclimated to walking on a treadmill. Each trial commenced with a 60-second warm-up period at the same velocity, immediately followed by a 2-minute race walk, during which all relevant measurements were meticulously recorded.

Measuring

The experiment employed a motorized treadmill, and the kinematic characteristics were assessed using the OptoJump Next optical system (Microgate, Italy). This system consists of two bars positioned at the same level as the treadmill belt, maintaining a 0% grade. Each bar is equipped with 32 LEDs that continually measure essential variables, including flight time, contact time, step length, step frequency, and others. Previous research, conducted by Hanley and Tucker (2019), has established the accuracy of the OptoJump Next equipment in measuring kinematic parameters specific to race walking.

Data analysis

Measurements using the OptoJump Next system were recorded at a sampling rate of 1 kHz. Prior to exporting the data from the OptoJump software, a minimum duration of flight and contact time was set to 1 ms.

For statistical analysis, we utilized the R Studio software (R Core Team, 2020). The raw data was not subjected to any filtering process. Data normality was assessed through the Shapiro-Wilk test and graphical analysis (Q-Q plots).

To compare sample variances, we employed the F-test, while differences in means were determined using the Welch Two Sample T-test, Paired T-test, or Wilcoxon rank test as appropriate. Pearson's product-moment correlation and Spearman's rank correlation were utilized to calculate the correlations between variables.

The research received approval from the Research Ethics Committee of the Latvian Academy of Sport Education under approval number: 2/47813.

Results

Flight and contact phase

RW1 and RW3 did not exhibit any steps without a flight phase, whereas RW2 experienced 11 steps without a flight phase at 13.3 km/h, 2 steps at 14.0 km/h, and 1 step at 15.0 km/h. In total, each participant performed 196-216 steps during each of the walking trials.

Table 3 presents the descriptive statistics of the flight and contact phase duration data, while Figure 1 provides a visual representation of the descriptive statistics. Additionally, Figure 2 showcases the correlations between relevant variables.

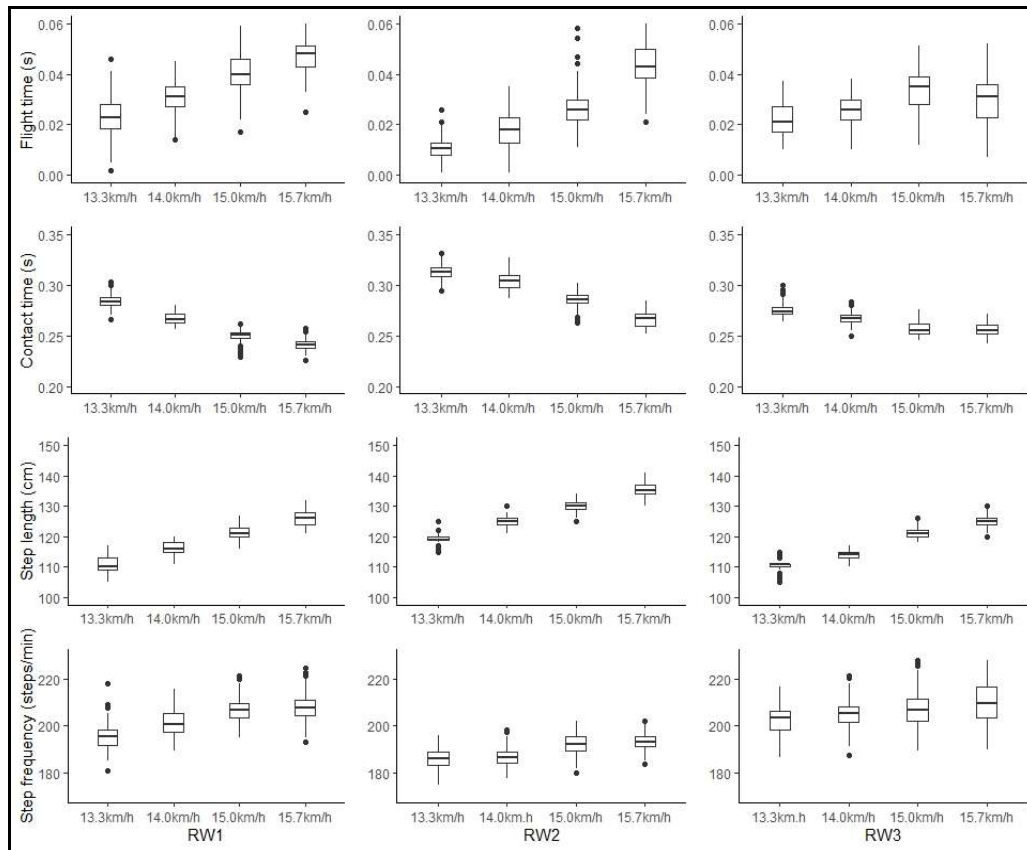


Fig. 1. Dynamics of flight time and contact time, step length and frequency

The findings of the study revealed a significant increase in the flight phase duration as the walking velocity increased ($p < 0.001$), with the exception of one instance for RW3, where the flight phase was longer at 15.0 km/h compared to 15.7 km/h ($p < 0.001$). Moreover, there was a positive correlation between flight time and walking velocity ($r = 0.806$; $p = 0.002$).

Table 3. Dynamics of flight and contact phase duration

	13.3 km/h		14.0 km/h		15.0 km/h		15.7 km/h	
	Flight phase	Contact phase	Flight phase	Contact phase	Flight phase	Contact phase	Flight phase	Contact phase
RW1								
MEAN	0.023s	0.284s	0.031s	0.267s	0.040s	0.250s	0.048s	0.241s
SD	0.007s	0.006s	0.006s	0.005s	0.007s	0.006s	0.007s	0.005s
CV	30.7%	2.2%	20.0%	1.9%	22.2%	2.2%	13.8%	2.0%
RANGE	0.002s - 0.046s	0.266s - 0.303s	0.014s - 0.045s	0.256s - 0.280s	0.017s - 0.059s	0.229s - 0.262s	0.025s - 0.063s	0.226s - 0.257s
RW2								
MEAN	0.011s	0.313s	0.018s	0.304s	0.026s	0.286s	0.044s	0.266s
SD	0.004s	0.007s	0.007s	0.008s	0.007s	0.007s	0.009s	0.007s
CV	40.8%	2.2%	37.9%	2.5%	40.6%	2.3%	19.4%	2.8%
RANGE	0.001s - 0.026s	0.294s - 0.331s	0.001s - 0.035s	0.287s - 0.327s	0.011s - 0.058s	0.263s - 0.302s	0.021s - 0.066s	0.252s - 0.285s
RW3								
MEAN	0.022s	0.275s	0.026s	0.267s	0.033s	0.258s	0.030s	0.256s
SD	0.007s	0.006s	0.005s	0.005s	0.009s	0.007s	0.009s	0.006s
CV	30.4%	2.2%	20.3%	1.9%	33.9%	2.7%	29.7%	2.3%
RANGE	0.010s - 0.037s	0.264s - 0.300s	0.010s - 0.038s	0.250s - 0.284s	0.012s - 0.051s	0.245s - 0.276s	0.007s - 0.052	0.242s - 0.272s

RW1, RW2, RW3 = identification of participant; MEAN = mean value; SD = standard deviation; CV = coefficient of variation

The results indicated a consistent decrease in contact time duration for all participants as the walking velocity increased ($p < 0.001$). However, similar to flight time, RW3 did not exhibit a significant change in contact time when the walking velocity increased from 15.0 km/h to 15.7 km/h ($p = 0.159$). Additionally, there was a negative correlation between contact time and walking velocity ($r = -0.673$; $p = 0.02$).

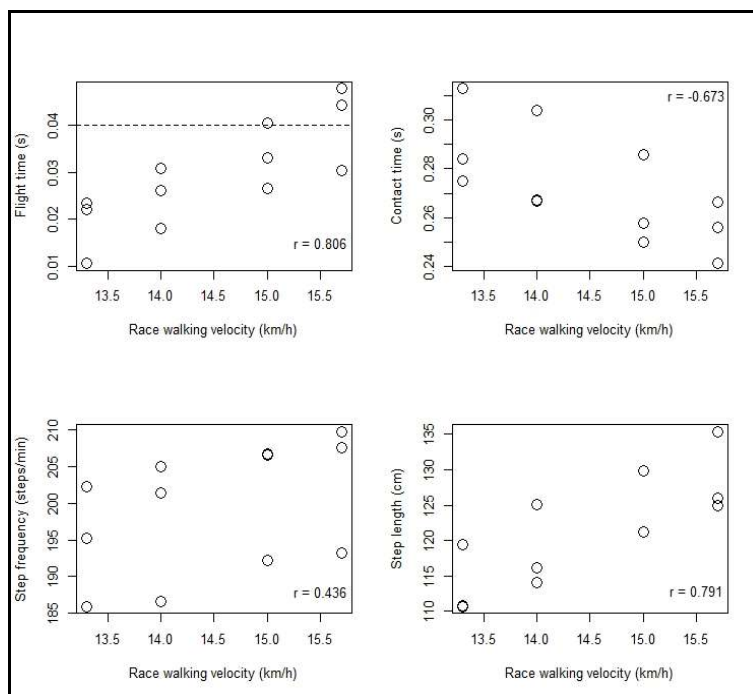


Fig. 2. Correlation between walking velocity and kinematical variables

The ratio between the swing and stance phases

The observed increase in flight times and decrease in contact time led to a broader distribution of the swing:stance ratio, with a slight rise in swing times and a reduction in stance times. These changes in the swing:stance ratio were consistent among all race walkers, although their specific values varied slightly (see Table 4). More comprehensive information on the calculation of "Ratio1" and "Ratio2" can be found in the discussion section.

Table 4. Swing: stance ratio (%) according to walking velocity

	Swing/stance ratio 13.3 km/h		Swing/stance ratio 14.0 km/h		Swing/stance ratio 15.0 km/h		Swing/stance ratio 15.7 km/h	
	Ratio 1	Ratio 2	Ratio 1	Ratio 2	Ratio 1	Ratio 2	Ratio 1	Ratio 2
RW1	52:48	54:46	53:47	55:45	54:46	57:43	55:46	58:42
RW2	51:49	52:48	51:49	53:47	52:48	54:46	54:46	57:43
RW3	52:48	54:46	52:48	54:46	53:47	56:44	53:47	55:45

RW1, RW2, RW3 = identification of participant; difference between Ratio 1 and Ratio 2 is described in the discussion part of the paper

Step length and frequency

Table 5 presents the descriptive statistics for step length and frequency, while Figure 1 provides a visual representation of these statistics. Additionally, Figure 2 illustrates the correlation between step length and velocity. The results demonstrated a significant increase in step length as race walking velocity increased in all cases ($p < 0.001$). The correlation coefficient between velocity and step length was found to be 0.791 ($p = 0.002$).

Regarding step frequency, RW1 exhibited significant changes when increasing velocity from 13.3 km/h to 14.0 km/h and from 14.0 km/h to 15.0 km/h ($p < 0.001$). However, there were no significant changes in step frequency between walking at 15.0 km/h and 15.7 km/h ($p = 0.052$). For RW2, step frequency did not change significantly when increasing velocity from 13.3 km/h to 14.0 km/h ($p = 0.111$). However, RW2 demonstrated a

higher step frequency at 15.0 km/h compared to walking at 14.0 km/h ($p < 0.001$), and there was also a significant difference in step frequency between 15.0 km/h and 15.7 km/h ($p = 0.018$) for the same participant. RW3 exhibited an increase in step frequency with higher walking velocity ($p < 0.001$), with a different p-value observed when increasing velocity from 14.0 km/h to 15.0 km/h ($p = 0.014$). Furthermore, the correlation between walking velocity and step frequency was not found to be significant ($p > 0.05$).

Table 5. Dynamics of step length and frequency

	13.3 km/h		14.0 km/h		15.0 km/h		15.7 km/h	
	Step length (cm)	Step freq. (s/min)	Step length (cm)	Step freq. (s/min)	Step length (cm)	Step freq. (s/min)	Step length (cm)	Step freq. (s/min)
RW1								
MEAN	110.9	195.3	116.2	201.5	121.2	206.6	126.1	207.6
SD	2.67	5.11	1.77	5.35	2.23	4.79	2.04	5.38
CV	2.4%	2.6%	1.5%	2.7%	1.9%	2.4%	1.6%	2.6%
RW2								
MEAN	119.4	185.9	125.1	186.6	129.8	192.3	135.4	193.2
SD	1.31	4.07	1.53	3.54	1.53	4.22	2.14	3.27
CV	1.1%	2.2%	1.2%	1.9%	1.2%	2.3%	1.6%	1.7%
RW3								
MEAN	110.7	202.3	114.0	205.0	121.3	206.7	124.9	209.8
SD	1.71	5.78	1.43	5.11	1.47	8.48	1.71	8.62
CV	1.5%	2.9%	1.3%	2.5%	1.3%	4.1%	1.4%	4.1%

RW1, RW2, RW3 = identification of participant; MEAN = mean value; SD = standard deviation; CV = coefficient of variation

Discussion

In this study, maintaining a double support phase was found to be a rare occurrence. Two of the race walkers did not perform any steps without a flight phase, and one race walker had less than 2% of their steps without a flight phase. It is noteworthy that having a flight phase during competitions is common among race walkers. Previous studies have suggested that a threshold of 0.04 seconds for flight phase duration is the upper limit that cannot be visually detected by judges (Knicker & Loch, 1990; De Angelis & Menchinelli, 1992). However, the question of whether walking with a small flight phase is in accordance with the rules remains unclear. The rule is strict - no visible flight phase with the human eye. But does this mean no flight time at all, or simply no flight time that is visible? It is still an ongoing debate.

Calculating and analysing the swing:stance ratio in race walking is not a straightforward task. It is influenced by various factors, including the presence or absence of a flight phase, and the relationship between double support time and both the current and following stance times. Additionally, flight time is a part of both the ongoing swing phase and the subsequent swing phase. In this study, two swing:stance ratios were calculated: (1) where flight time is included as part of the ongoing swing, and (2) where the flight phase is included as part of both the ongoing and the next swing phase. Future research would benefit from a more detailed description of the methodology used to calculate the swing:stance ratio, as different ratios have been reported in previous studies. Theoretically, the swing time should be equivalent to the stance time of the opposite foot, as it occurs during the stance phase of the opposite foot. In this study, the contact times showed minimal variation, with coefficients of variation (CVs) ranging from 1.9% to 2.8% for different participants. However, the flight times varied significantly, with CVs ranging from 13.8% to 40.8%. This may partly explain the changes observed in the swing:stance ratio, favouring a longer swing phase and resulting in a greater overall duration of the swing phase (Knicker & Loch, 1990).

The inclusion of a flight phase in race walking technique is a topic of discussion. In this study, it was observed that the duration of the flight phase increased with the velocity of race walking but remained below 0.04 seconds even at speeds of 13 km/h and 14 km/h. Interestingly, at 15 km/h, participants were able to maintain an average flight time duration below the mentioned limit, although this velocity is relatively high for them. Notably, RW3 managed to stay within these limits even while walking at world record speed. Considering this issue from a flexible perspective, a threshold of 0.04 seconds or some other value could potentially be used to introduce an electronic control system in race walking competitions (De Angelis & Menchinelli, 1992). Wearable devices and online control systems could be utilized to ensure transparency and fairness in competition, while also providing interesting information for spectators, coaches, and athletes. Such an electronic system could allow for monitoring and control of the "flight phase rule" during both competition and

training conditions, while also allowing for possible deviations from the threshold (Di Gironimo et al., 2017). Further research is needed to define these values more precisely.

This study provides valuable insights into the complex relationship between race walking technique, velocity, and compliance with competition rules. The findings highlight the importance of maintaining flight time duration within specified threshold levels to adhere to competition rules, with higher velocities showing mixed effects (Knicker & Loch, 1990; De Angelis & Menchinelli, 1992). The study contributes to the understanding of race walking biomechanics and the ongoing debate regarding the flight phase as a part of the technique or a violation of the rules. The flight phase can be observed in running (Bernans, 2023), but it is not the sole differentiating factor between running and race walking from a biomechanical perspective (Norberg, 2015; Pavei et al., 2014). Furthermore, the potential use of wearable devices (Caporaso et al., 2019; Oks et al., 2017) and online control systems to monitor flight time duration in race walking competitions and ensure transparency and fairness is discussed (Taborri et al., 2019). The study's findings pave the way for further research in this area, including defining threshold values and exploring the implementation of electronic control systems (Norberg, 2015).

In this study, three different cases were analysed, resulting in three outcomes for our hypothesis. The hypothesis was found to be true for RW1, partly true for RW2 (as he exceeded the threshold at 15.7 km/h), and not true for RW3, as he maintained an average flight phase duration below 0.04 seconds (Knicker & Loch, 1990; De Angelis & Menchinelli, 1992). This also emphasizes the necessity of conducting individual case studies to investigate this problem, as each athlete may exhibit unique results. Athletes have expressed concerns regarding the use of "arithmetic averages" to address such issues, considering the numerous individual characteristics and differences among them.

Conclusions

In conclusion, our study revealed that race walkers were able to maintain flight time durations below the threshold of 0.04 seconds during walking at their competition velocity. However, at higher velocities, the impact on flight time was varied. Instances of steps with double support were infrequent, occurring less than 2% of the time or only on a few occasions during race walking at competition velocity.

Our findings suggest that while the flight phase can be considered a natural component of the race walking cycle, it is crucial to keep it within the specified threshold levels to ensure compliance with competition rules. Further research and the potential implementation of electronic control systems could play a vital role in enforcing these rules and providing valuable insights for athletes, coaches, and spectators.

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