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Kinematic Analysis of Support Phase Characteristics in Women Race Walking

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Abstract: Race walking requires a great deal of effort to compete successfully which includes a unique combination of technique, extreme physical exertion and mental focus. Unlike running, race walking is composed by support phase (heel strike, mid-stance and toe off) and swing phase. The aim of this study was to analyze the association between different kinematic characteristics of support phase during race walking and walking velocity. The rules of race walking demand that no visible flight time should occur and the stance leg must be straightened from initial contact to midstance. Previous research has not examined whether these rules also have an effect on walking performance and what consequences might arise. Top ten (U-20 Girls) finishers of 10000m race walk discipline, 33rd National Junior Athletic Championships, 2017 held at Acharya Nagarjuna University, Vijaywada, A. P. India were recorded by using two Nikon digital 4K camcorders (60 Hz) mounted on rigid tripods were placed alongside of the course at approximately 90° to the plane of motion. The junior athletes were analyzed by using motion analysis software (KINOVEA 0.8.27). Descriptive statistics and Pearson Product Moment Correlation coefficient ($p<0.05$) were employed for statistical calculation. The tabulation of data was done by using the IBM SPSS 25 software. The result of the study revealed that, women athlete's performance were affected by the long contact phase duration (Mean=0.33 s (±) 0.05). This factor relativity creates hindrances in propulsive phase. A negative association ($r= -0.49$) found between contact time and average speed. As expected, due to the technical rules of this discipline knee angel at heel contact is significantly correlated with velocity as the calculated r value was 0.709* (Critical value at 8 df $r = 0.632$). Whereas, at mid stance phase a negative correlation found between knee angle and walking performance that sketch a hyper extended knee. However, a positive linear relationship found in variables like, hip angle, elbow angle at heel contact and mid stance phase with walking velocity. But, a less economical technique observed in toe off phase for almost every variable as those were negatively associated with mean speed, and so a balance between those fundamental techniques of support phase variables is advisable. The race walkers had shorter swing times, longer contact times, and smaller maximum knee flexion angles (152° ± 7.32) than the distance runners. The smaller knee flexion angles in race walkers meant they experienced greater swing leg moment of inertia than the distance runners.

Keywords: Gait Cycle, Pedestrian, Vertical Upright Position, Propulsion Etc.

1. Introduction

Race walking requires a great deal of effort to compete successfully which includes a unique combination of technique, extreme physical exertion and mental focus. Unlike running, race walking is composed by support phase (heel strike, mid-stance and toe off) and swing phase. It is the part of the athletics programme at the Olympic Games and all other major athletics championships. Championship competitions are held over 20km for men and women, and 50km for men only. Races for junior men and women (under 20 years of age) are held over 10km. Race walking is governed by strict biomechanical rules, as athletes are not allowed to have any visible loss of contact with the ground and must maintain a straightened knee from the initial contact with the ground until the vertical upright position Rule 230.54.2 [16]. The standard Race Walking Distances are: indoor: 3000m; 5000m; outdoor: 5000m, 10km, 10,000m, 20km, 20,000m, 50km, 50,000m (Rule 230.54.1).

History

Race walking dates back from the 17th and 18th centuries. The first competitors were the footmen who would run and/or walk by the side of their masters' coaches. The aristocracy of the day began to stake wagers as to which of their footmen would win a race – some of which lasted for six days! – and the sport became an increasingly popular professional activity during the 19th century, when it was known as 'pedestrianism'. Race walking first appeared at the Olympics in 1904 with a half-mile race that was part of the 10-event 'All-Around Championship', an early forerunner of the decathlon. Individual races, initially over shorter distances than are common today were introduced at the Intercalated Games of 1906 and, apart from the 1928 Amsterdam Games, have been a fixture at Olympic Games and IAAF World Championships ever since.

The 20 km race walk has been contested by men at the Olympic Games since 1956. Women first competed in race walking at the 1992 Olympic Games, initially over 10 km. They stepped up to 20 km in 2000. Russia and China are currently the dominant nations in both the men's and women's 20 km events. China's Chen Ding made history at the 2012 Olympics by not only setting an Olympic record of 1: 18: 59 by 13 seconds in the men's event but also by becoming the youngest ever race walk gold medalist, just one day short of his 20th birthday. The two countries took the top six places in the women's race in London.

Though race walking might seem to be a somewhat neglected athletics discipline, it is certainly the most controversial. This has to do with the judging of the strict rules by which it is governed. As in the running events, the fastest athlete is declared the winner of a race walking competition. Unlike runners, all athletes must move along the course without exceeding a certain critical velocity that would cause a flight phase in the stride and thus violate World Athletics Rule 230.54.2 Race walking. Therefore, is to certain degree paradoxical: race walkers are required to be as fast as possible but not so fast that they start running.

It is very useful to measure biomechanical and variables across large groups of athletes, it is equally valuable to focus on performances of the very best athletes in understanding the determinants of fast race walking. In race walking, the single most important factor in competitive success is velocity. At the most basic level, velocity is determined by step, or stride, length and stride frequency. The position of the support foot in relation to the athlete's whole body center of mass is important in maintaining forward speed [10]. A foot landing too far in front of the body at initial contact can cause too great a braking impulse [11]. The distance to the support foot at toe-off is important in generating adequate stride length and forward propulsion [7]. In a study carried out by Hanley, Bissas, & Drake, 2013 [5] found a distinct gait pattern and the need of not only endurance capacity, but also a great technical ability to perform at elite level. For example, non-peer reviewed evidence suggests that when race walking, the optimum foot position at initial contact is directly under the center of mass, as a foot ahead approaching zero would result in considerably reduced braking forces and, therefore, help maintain forward momentum [14].

A subsequent reduction in step length, which contrasts with research suggesting that larger step lengths would contribute to faster race walking speeds in elite race walkers [9]. Other researchers have reported smaller vertical oscillations and longer flight times as key factors for increased walking speeds [4, 6]. Success in race walking is related more to the efficiency of technique rather than physiological factors [8]. The correction and optimization of technique is therefore of great importance. Modifications in gait patterns may affect the energy cost of walking and these modifications can be caused by fatigue [1]. These changes usually occur at the end of a race or within the final stages, when the final outcome is decided. This is especially important in race walking, where poor technique can lead to disqualification. In order for athletes to improve their overall performance, knowledge of when their technique starts to change and ways to combat changes may help prevent technique deterioration.

A technical guideline of variables are most important to race walking success that can then be considered and used by athletes and coaches to highlight indicators of elite performance. Due to the same consequences it was so important to analyze the association between velocity and different kinematic characteristics of support phase during race walking.

2. Objectives

The purpose of the study was to analyze and investigate the association and relation of kinematic properties of support phase with the walking speed. There were two objectives towards achieving this aim;

1. Firstly, to find out associations of performance within the important kinematic (linear) variables of support phase that can suggest methods of improving performance.
2. Secondly, to measure significance of the angular kinematical properties of joints at different position of support phase with race walking (RW) performance.

3. Methodology

3.1. Subjects

From 33rd National Junior Athletic Championships, 10000 m race walk discipline (Acharya Nagarjuna University, Vijaywada, A. P. India, 2017) top ten female race walkers of U-20 age group were recorded and analyzed as a subject of the study.

3.2. Criterion Measures

Table 1. *Details of selected physiologic and kinematic variables.*

Criterion	Measure
KINEMATIC PARAMETER	
Speed	m/s
Contact time	s
Angular kinematics at Support Phase (Heel strike, Mid Stance and Toe Off)	
Knee angle	Degree
Hip angle	Degree
Ankle angle	Degree
Shoulder angle	Degree
Elbow angle	Degree

3.3. Procedure of Data Collection

For kinematic analysis, athletes were recorded as they passed through halfway (4550 m) at back straight on the 400 m track by using two standard digital HD camcorders (Nikon B700, 60Hz) mounted 90° angles on two rigid tripods 4 m away from the track inside & outside where reference volume was 5 m long and 1.5 m high. The video data were analyzed by using motion analysis software (KINOVEA 0.8.27).

3.4. Statistical Technique

Descriptive statistics & Pearson's product moment correlation coefficient were employed to find the associations of RW performance with the kinematic variables. The significance level was set at 95% of confidence ($p<0.05$). The tabulation of data was done by using the IBM SPSS 25 software.

4. Findings and Discussions

The mean values presented in Table 2 show an average speed of 3.69 m/s which paint an exact image how the elite junior female race walkers in the nation stride forward at speeds approaching 13.28 kph. Average knee angle in heel strike phase in elite girl's athlete is 181° whereas; a hyper extended knee angel found (188°) at vertical upright position which shows difficulty to propel forward by overcoming Center of Mass.

Race walkers were having high contact time with an average of 0.33 sec that causes a negative effect in performance.

Whereas, mean hip angle and ankle angel at heel contact found 162° & 102° that was positively associated with performance. But, at vertical upright position (mid stance phase) of contact phase a negative association observed in knee angle, ankle and shoulder angel.

Table 2. *Mean and (± s) between-subjects effects of key race walking variables. Differences were significant at p < 0.05 (bold).*

Descriptive Statistics							
		N	Minimum	Maximum	Mean	Std. Deviation (±)	r
	Ave. Speed (m/s)	10	3.45	4.03	3.69	0.19	
	Contact Time (s)	10	0.24	0.39	0.33	0.05	-0.49
Knee Angle (°)	Heel Strike Phase	10	177	184	181.00	2.11	.709*
	Mid-Stance Phase	10	185	192	188.00	2.45	-.247
	Toe Off Phase	10	144	165	152.00	7.32	.801**
Hip Angle (°)	Heel Strike Phase	10	154	170	162.00	6.16	.745*
	Mid-Stance Phase	10	181	195	189.00	4.71	.810**
	Toe Off Phase	10	183	210	196.00	7.96	.531
Ankle Angle (°)	Heel Strike Phase	10	93	115	102.00	6.41	.399
	Mid-Stance Phase	10	101	111	106.00	3.74	-.257
	Toe Off Phase	10	113	146	126.70	9.38	.661*
Shoulder Angle (°)	Heel Strike Phase	10	40	71	53.00	11.48	.764*
	Mid-Stance Phase	10	72	92	84.30	5.87	-.045
	Toe Off Phase	10	88	109	98.00	7.09	.862**
Elbow Angle (°)	Heel Strike Phase	10	59	83	67.00	7.72	.753*
	Mid-Stance Phase	10	65	84	76.00	6.13	.742*
	Toe Off Phase	10	40	84	63.00	16.44	-.427

Table 3. *Correlation of key race walking variables across the 33rd National Junior Athletic Championships, 2017, Race Walk discipline, U-20 Women Top Performers. Correlations were significant at p < 0.05 (bold).*

Correlations						
			Ave. Speed (m/s)	Heel Strike	Mid Stance	Toe Off
Ave. Speed (m/s)		Pearson Correlation	1	.709*	-.247	.801**
Knee Angle (°)	Heel Strike	Pearson Correlation		1	-.452	.648*
	Mid-Stance	Pearson Correlation			1	-.291
	Toe Off	Pearson Correlation				1
		N	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

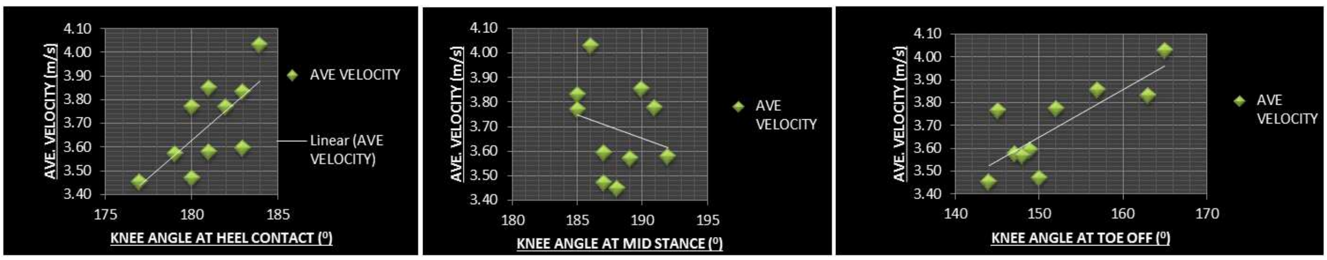

Figure 1. *Scatter Plotting of Knee angle.*

Table 4. *Correlation of key race walking variables across the Junior National women's Top Performers. Correlations were significant at p < 0.05 (bold).*

Correlations						
			Ave. Speed (m/s)	**Heel Strike**	**Mid Stance**	**Toe Off**
Ave. Speed (m/s)		Pearson Correlation	1	.745*	.810**	.531
Hip Angle (°)	Heel Strike	Pearson Correlation		1	.585	.424
	Mid-Stance	Pearson Correlation			1	.791**
	Toe Off	Pearson Correlation				1
		N	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

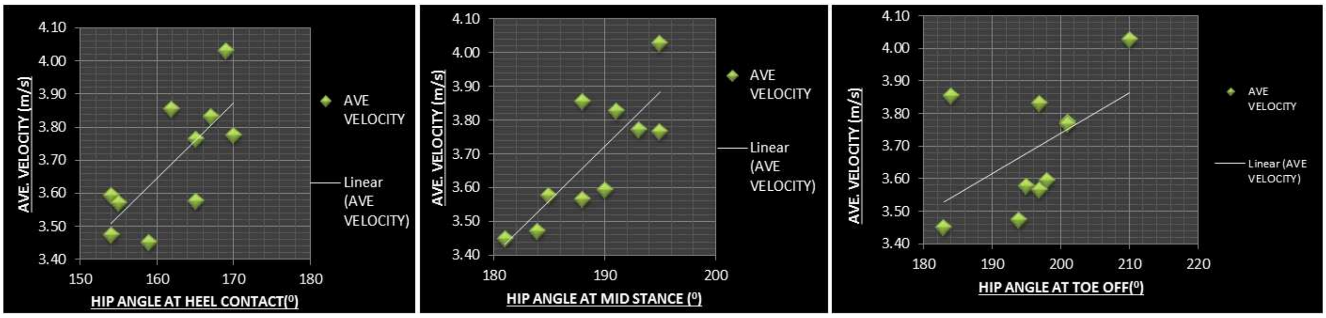

Figure 2. *Scatter Plotting of Hip angle.*

Table 5. *Correlation of key race walking variables across the Junior National women's Top Performers.*

Correlations						
			Ave. Speed (m/s)	**Heel Strike**	**Mid Stance**	**Toe Off**
Ave. Speed (m/s)		Pearson Correlation	1	.399	-.257	.661*
Ankle Angle (°)	Heel Strike	Pearson Correlation		1	.023	.216
	Mid-Stance	Pearson Correlation			1	.367
	Toe Off	Pearson Correlation				1
		N	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed)

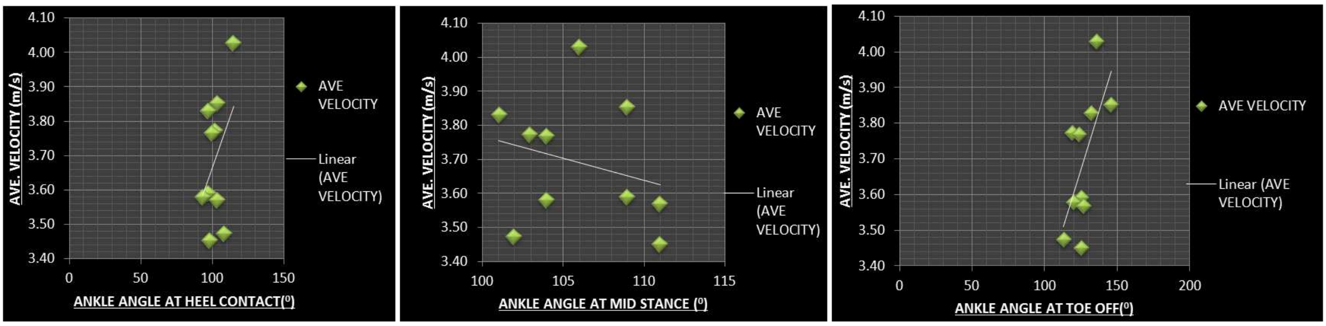

Figure 3. *Scatter Plotting of Ankle angle.*

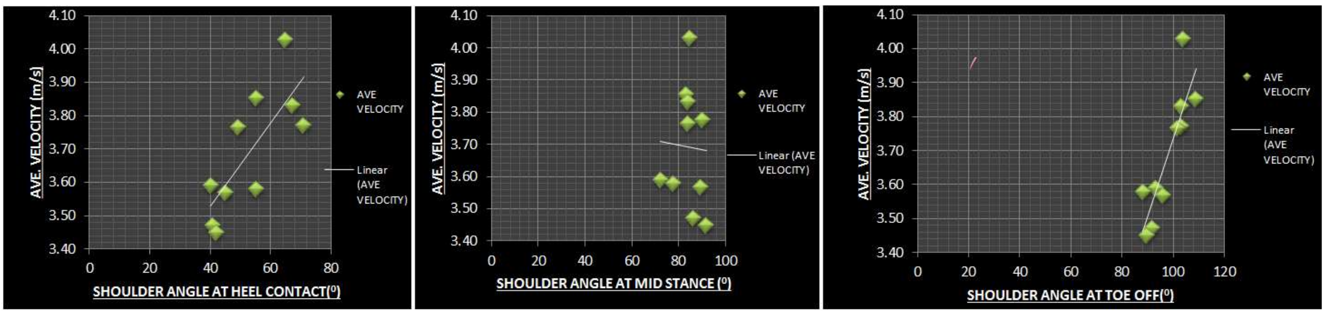

Figure 4. *Scatter Plotting of Shoulder angle.*

Table 6. *Correlation of key race walking variables across the Junior National women's Top Performers. Correlations were significant at p < 0.05 (bold).*

Correlations						
			Ave. Speed (m/s)	**Heel Strike**	**Mid Stance**	**Toe Off**
Ave. Speed (m/s)		Pearson Correlation	1	.764*	-.045	.862**
	Heel Strike	Pearson Correlation		1	.181	.627
Shoulder Angle (°)	Mid-Stance	Pearson Correlation			1	.158
	Toe Off	Pearson Correlation				1
		N	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 7. *Correlation of key race walking variables across the Junior National women's Top Performers.*

Correlations						
			Ave. Speed (m/s)	**Heel Strike**	**Mid Stance**	**Toe Off**
Ave. Speed (m/s)		Pearson Correlation	1	.753*	.742*	-.427
	Heel Strike	Pearson Correlation		1	.749*	.032
Elbow Angle (°)	Mid-Stance	Pearson Correlation			1	-.178
	Toe Off	Pearson Correlation				1
		N	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

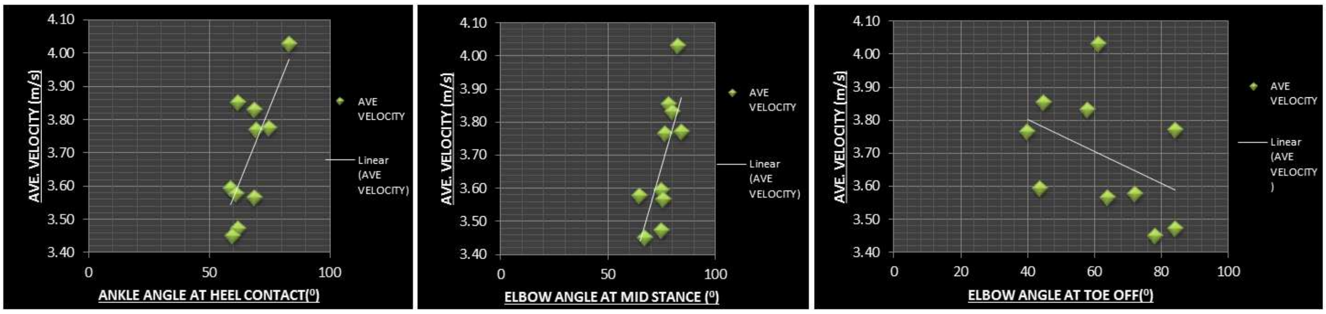

Figure 5. *Scatter Plotting of Elbow angle.*

The result of the study revealed that, women athlete's performance were affected by the long contact phase duration (Mean=0.33 s (±) 0.05). This factor relativity creates hindrances in propulsive phase. A negative association (r= -0.49) found between contact time and average speed.

As expected, due to the technical rules of this discipline knee angel at heel contact is significantly correlated with velocity as the calculated r value was 0.709* (Critical value at 8 df r = 0.632). Whereas, at mid stance phase a negative correlation found between knee angle and walking performance that sketch a hyper extended knee. However, a positive linear relationship found in variables like, hip angle, elbow angle at heel contact and mid stance phase with walking velocity. But, a less economical technique observed in toe off phase for almost every variable as those were negatively associated with mean speed, and so a balance between those fundamental techniques of support phase variables is advisable. The athletes adhered very closely to the race walking rule with regard to having a straightened knee at first contact; however, they were closer to the threshold of visibly losing contact. While there was little variation between athletes in terms of hip and knee angles, there were larger variations found within the measurements of shoulder and elbow angles. Coaches and athletes should be mindful that race walking is a whole-body activity and inefficient movements should be identified and corrected as appropriate. The race walkers had shorter swing times, longer contact times, and smaller maximum knee flexion angles (152° ± 7.32) than the distance runners (56° ± 6). The smaller knee flexion angles in race walkers meant they experienced greater swing leg moment of inertia than the distance runners but there were few associations in either group between knee flexion angle and moment of inertia with key performance parameters. Swing phase kinematics in race walking are restricted by the rules of the event and result in knee angular motions different from those in distance running, preventing race walkers from reaching the speeds attainable by distance runners.

Figure 6. *Chief Judge plotting the red cards for walking fouls in 33rd National Junior Athletic Championships 2017 held at Acharya Nargarjuna University, Vijaywada, A. P. India.*

Figure 7. *Top performer of U-20 Women 10000 m Race Walking 1st Bandana Patel (Uttar Pradesh) Timing: 52: 02.55 sec, 2nd Priyanka Patel (Uttar Pradesh) Timing: 52: 16.54 sec and 3rd Sonal Sukhwal (Rajashtan) Timing: 52: 34.18 sec.*

Stride frequency is determined by the time taken to complete each successive step, and as a result a shorter step time (usually the result of a shorter contact time) is associated with higher walking speeds [2].

Whereas variables like, flight time, flight distance and C of G distance were significantly associated with the walking performance. De Angelis and Menchinelli (1992) [3] analyzed 14 km/h just in the limit of what is perceptible to the human eye. World-class race walkers can compete at fast speeds without a visible loss of contact with the ground. This finding suggests that the most economical race walkers are those exhibiting shorter flight times at a given speed, resulting in a safer race walking technique in terms of risk of disqualification.

Most of the calculated “r” values were significant at 0.05 level as the critical value of 8 df is r = 0.632. Due to the direct association may be this type of result found in different phases of race walking. High degree of positive linear association found in walking velocity with knee, hip, elbow, shoulder and ankle angle. There is a direct link between the position of the foot and the joint angles of the entire leg. First, the hip angle will determine how far in front or behind the body the foot is placed. Increasing hip extension velocity results in a decrease in support time [13] which in turn allows for much longer strides to be taken. Second, the knee is in many regards the most important joint to analyze during race walking as it is the only joint to which specific technical rules are applied. Although an extended knee is abnormal during normal walking or running, research has shown that a straight knee at landing is of benefit to race walkers [12]. Finally, the angle of the ankle at different points in the support phase is important: at initial contact for ensuring a straightened knee and at toe-off as its plantar-flexion aids the drive phase of the step [15].

5. Conclusions

From above all discussions, it can be concluded that race walking performance was positively associated with the race walking economy which implies that the fastest race walkers were more economical than the lesser performers. In relation to RW technique and forward propulsion, support phase duration from heel strike through mid stance to toe off plays most vital role with all major angular characteristics of different joints. Similarly, race walking performance and technique were significantly related to knee, hip, elbow, shoulder joints angel at the heel contact phase of gait cycle (Support phase i.e. heel contact, mid stance & toe off) which highlights the importance of race walking biomechanics for elite competitors in this sport. In this regard, shorter flight phase (below of what is perceptible for the human eye) and longer Support phase may reduce the aerobic capacity and efficiency of race walking in world-class female race walkers. Since the rules of the sport penalize a visible lost of contact with the ground, coaches and race walkers should avoid modifying their race walking style by increasing flight times, as it may not only obstruct the velocity, but also lead to disqualification from the race.

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