Original Article

Effect of speed change on the kinematic parameters of women's 20 km race-walking: A case study

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Abstract:

This study aims at exploring the effect of speed change (i.e., 13.2 km/h moderate-speed and 15.12 km/h high-speed) on kinematic parameters of women's 20 km race walking. C.N, Tunisian elite women's champion (i.e., Arabic, African and U23 Mediterranean champion) qualified for the Rio 2016 and Tokyo 2020 Olympic Games (age 22.15 years; height 1.68 m; mass 50.2 kg; average training 140 km/week) who participated in this study. A 3D kinematic analysis of multi-speed race walking (i.e., over a distance of 20 m) was recorded using two mutually synchronized digital cameras (i.e., AEE PNJ Cam, 120 Hz). Body markers (i.e., Hanavan model) were digitized using SkillSpector® software. Delta percentage between moderate and high-speed parameters were calculated. The results showed that when changing speed (i.e., from moderate-speed to high-speed), stride length (i.e., 1.33 m and 1.45 m respectively) and stride frequency (i.e., 3.5 Hz and 4 Hz respectively) change as well as contact time (i.e., 0.23 s and 0.20 s respectively). However, center of mass vertical displacement (i.e., 0.064 m and 0.063 m respectively), knee angle in flexion (i.e., 84.09° and 85.01° respectively) and in extension (i.e., 180.02° and 180.01° respectively) remain almost constant, which shows that the athlete has an excellent technical stability. In conclusion, the athlete has retained the same technique, even during speed increase, there is no perceptible change in either vertical displacement or knee angle, but an increase in the frequency and length of the stride, thanks to the high technical requirements and to avoid disqualification risk due to the strict race rules.

Key Words: Kinematic analysis; moderate-speed; high-speed; frequency; stride length

Introduction

In literature, several authors have studied race-walking from a technical (Caporaso, Grazioso, Panariello, Di Gironimo, & Lanzotti, 2019; Di Gironimo, Caporaso, Del Giudice, & Lanzotti, 2017; Taborri, Palermo, & Rossi, 2019), physiological (Gomez-Ezeiza, Torres-Unda, Tam, Irazusta, Granados, & Santos-Concejero, 2018; Pavlovi & Mihajlovic, 2020; Salamuddin, Harun, & Abadi, 2014) and biomechanical (Bej, D2020; Koji, Hirokawa, Sugita, Enomoto, Kadono, & Suzuki, 2020; Pavei & La Torre, 2016; Pšurný, Janura, Svoboda, & Kopynová, 2017; Sovenco & Danilyuk, 2017; Xin et al., 2020) point of view, in men's and women's athletes.

Race-walking is a very difficult event that requires both physical endurance and technical ability (Hilliard, 1986). In this event, the athlete must walk as fast as possible, following the technique which is determined by the competition rules (Cazzola, Pavei, & Preatoni, 2016). Each race-walking stride comprises a single support phase (i.e., divided into front and rear support phases) and a double support phase. So, the single support phase provides acceleration and includes preparation for planting the foot of the free leg and the double support phase is necessary to maintain ground contact at all times. That's why, two basic rules define race-walking: one foot must be on the ground at all times, the front foot must make contact before the rear foot leaves the ground and the support leg remains extended as long as possible and point of foot straight ahead and rolls along the outside edge of the sole up to the tip of the toes (Caporaso et al., 2019; Di Gironimo et al., 2017; Taborri et al., 2019). Referring to IAAF Rule 230.1, "Race-walking is a progression of steps so taken that the walker makes contact with the ground, so that no visible (i.e., to the human eye) loss of contact occurs. The advancing leg must be straightened (i.e., not bent at the knee) from the moment of first contact with the ground until the vertical upright position". So, race-walking is a highly technical event with very specific rules (Schiffer, 2008). Thus, to succeed in race-walking, a number of gait variables (i.e., speed, stride length, frequency, knee angle and vertical displacement) are essential (Hanley, 2019).

Success in competitive race-walking, from a biomechanical point of view, is essentially due to having a faster average walking speed than other athletes. The two principal factors that influence race-walking speed are step length and frequency (Knicker & Loch, 1990; Koji et al., 2020; Sovenco & Danilyuk, 2017). It is revealed that once step length has been maximized by the loss of visible contact with the ground and the increasing speed in race-walking which depends on increasing frequency (Cairns, Burdette, Pisciotto, & Simon, 1986; Koji et al., 2020; Swan, Byrnes, & Haymes, 1997; Sovenco & Danilyuk, 2017). However, race-walking speed is restricted

by two event's rule such as knee bent and flight. Therefore, success in race-walking competition depends not only on walking speed but also on the athlete's ability to maintain a gait pattern in respecting the rule.

Added to that, the knee joint is one of the most important factors to be assessed in race-walking techniques, since the rules require that the knee must be fully extended from the initial contact through to the vertical upright position (Bej, 2020; Koji et al., 2020; Villa, 1990). Cairns et al. (1986) defined Knee joint angles as hyperextended if they are greater than 175° . Similarly, Hanley, Bissas, and Drake (2013) stated the same definition for angles greater than 180° . While, Knicker and Loch (1990) showed a straightness between 175° to 185° . Moreover, an accentuated knee joint will influence time contact which must be minimized to consequently improve race frequency. Hanley (2014) confirmed that greater knee angles are associated with faster speed, shorter contact time and longer flight time. In addition, race-walking rules require a straight knee position during the braking and the propulsion phases which have the effect of abruptly raising the center of mass (COM) at a time when it is already risen (Bej, 2020; Cairns et al., 1986; Koji et al., 2020). Furthermore, Knee hyperextension and Pelvic obliquity are considered by Cairns et al. (1986), the primary cause of the decrease in vertical displacement of the COM.

Few women's racewalkers technical and biomechanical research was published in literature. Hanley et al. (2011) performed a 3D analysis of step length and cadence in women's racewalkers. Likewise, Sovenco and Danilyuk (2017) analyzed the major kinematic characteristics of the race-walking techniques of skilled junior female athletes. As well as, Bjet (2020) studied the different kinematic characteristics of walking velocity in women's racewalkers. Finally, Koji et al. (2020) investigated the mechanical factors to obtain a high walking speed in world elite women's 20-km walking race. Basing on the previous studies (Bjet, 2020; Hanley et al., 2011; Koji et al., 2020; Sovenco & Danilyuk, 2017) and what success in race-walking competition require technically, our study has focused on a new motion analysis protocol for women elite racewalker at different speed to demonstrate the effect of speed-change on kinematic parameters.

Material & methods

Participants

C.N., Tunisian elite women's racewalker, U23 Mediterranean champion, Arab and African Champion, women Tunisian record in 20 km race-walking [1 h 32 min 20 s] qualified for the Rio 2016 and Tokyo 2020 Olympic Games (age 22.15 years; height 1.68 m; mass 50.2 kg; average training 140 km/week) participated in this study. Being informed in advance of the experimental design, procedures, methods, benefits and possible risks involved in the study, the participant has to read and sign an informed consent before participating. Out of respect for research ethics, the experimental protocol was performed in accordance with the latest version of the Declaration of Helsinki for human experimentation and was approved by the local Ethical Committee.

Experimental design

Three-dimensional (3D) kinematic analyses of two 20 m race-walking sequences at different speeds (i.e., 13.2 km/h moderate-speed and 15.12 km/h high-speed) performed during a simulated competition with two mutually synchronized [Time Code Synchronization, TC-Link] digital cameras [PNJ Cam AEE, Action Cam SD18, 5MP CMOS optical sensor, $f / 2.8$ lens, 135° wide angle, shutter speed $1 / 4 - 1 / 10000$ s, acquisition frequency 120Hz, 720p]. Cameras were placed 13-m away and 1.50 m above the floor with an angle of 60° and 120° for the first and the second camera, respectively. To collect kinematic athlete walking data, twenty markers were attached to the body for digitization. Body markers, using the Hanavan model modified by De Leva (1996), were digitized using the video-based data analysis system SkillSpector® 1.3.2 [Odense SØ – Denmark], (Amara, Mkaouer, Chaabène, Negra, & Ben Salah, 2019; Mkaouer, Chaabene, Amara, Nassib, Negra, & Jemni, 2018; Mkaouer, Jemni, Amara, Chaabène, & Tabka, 2013). Similarly, the body segments' COM was computed using the Hanavan model modified by De Leva (1996) (figure 1).

Fig. 1: Measurement procedure.

Procedures

After a free warm-up (i.e., 15 min), the athlete started an official race-walking course (i.e., 20 km), from the 14th km, the athlete came into athletic track (i.e., in the sixth hallway) and performed two laps at moderate-speed (i.e., 13.2 km/h). A first gait analysis (i.e., at moderate-speed) was carried out at the start of the third lap (i.e., first straight line of the track). Then, in the fourth and fifth laps, the athlete increased speed gradually to reach a high-speed (i.e., 15.12 km/h). A second gait analysis (i.e., at high-speed) was carried out at the start of the sixth lap (i.e., first straight line of the track). Finally, the athlete continues the simulated competition on the track. The walking speed is controlled at each lap of the track by a GPS (i.e., Cross-Call Axion X3). The video acquisition of each walking speed (i.e., at 13.2 km/h and 15.12 km/h) was carried out during the passage in the straight line over a distance of 20m (i.e., marked by landmarks) at each start laps (i.e., third and sixth laps). Two national walking judges were present to validate the two analysis sessions. The environmental conditions recorded during the experience were 25°C for temperature and $w = 0.10 \text{ m}\cdot\text{s}^{-1}$ for wind velocity.

Data collection and analysis

Based on the literature review of Pavei, Cazzola, La Torre, and Minetti (2015), the works of Bej (2020), Koji et al. (2020), Hanley, Bissas, and Drake (2011), Hanley, Tucker, and Bissas (2018) and the biomechanical model of Hanley (2014, 2019), who presented a hierarchical model of race-walking (Figure 2) where he mentioned that the two most important aspects of race-walking hierarchical model are: knee extension, from initial contact to midstance, and no visible loss of contact. Also, flight time, as a cadence determinant, and knee angle, as a postural aspect, are the most important rules factors. In addition, the two main components of race-walking speed as shown in the model are step length (i.e., foot ahead / behind body) and cadence (i.e., contact time and flight time).

In this regard, we retained the following variables in the kinematic analysis:

- Speed (km/h)
- Contact time (sec)
- Stride length (m)
- Vertical displacement of COM (m)
- Knee angle in flexion (°)
- Knee angle in extension (°)
- Frequency of strides (Hz)

Delta-percentage (Δ) between speeds (i.e., moderate-speed MS and high-speed HS) " $\Delta (\%) = [(HS - MS) / MS] \times 100$ " was calculated in order to evaluate the percentage of variation (Amara, Nassib, & Mkaouer, 2015).

Fig. 2: Model of walking race (Hanley, 2019).

Results

The result of kinematic analysis of Tunisian champion women race walking at two different speeds (MS = 13.2 km/h and HS = 15.12 km/h) is presented in table 1.

Table 1. Result of kinematic analysis of Tunisian champion woman race walking

Variables	Moderate Speed (13.2 km/h)	High Speed (15.12 km/h)	Delta variation (Δ)
Contact time (s)	0.23	0.20	-13.04
Stride length (m)	1.33	1.45	9.02
COM Vertical displacement (m)	0.064	0.063	-1.56
Knee angle in flexion ($^{\circ}$)	84.09	85.01	1.09
Knee angle in extension ($^{\circ}$)	180.02	180.01	0.00
Frequency of strides (Hz)	3.5	4.0	14.29

We note a high variation in the contact time, stride length and frequency (figure 3a and 3b).

Fig. 3: Frequency of strides, (a) at moderate-speed (13.2 km/h) and (b) at high-speed (15.12 km/h)

Discussion

The aim of this research is to study the effect of speed change (i.e., 13.2 km/h and 15.12 km/h) on kinematic parameters of women's 20 km race walking. C.N, Tunisian elite women's racewalker (i.e., Arabic, African and U23 Mediterranean champion) qualified for the Rio and Tokyo 2020 Olympic Games participated in this study.

The results showed that when changing speed, stride length changes. Vice versa, Douglass and Garrett (1984) and Padulo et al. (2013) indicated that changes in stride length and frequency lead to changes in speed. However, Hanley et al. (2011) and Sovenco and Danilyuk (2017) showed that the single most important factor in race success is walking speed, which is the product of step length and frequency. Although, this is restricted by the two unique rules of race walking (i.e., knee bent and flight). Indeed, C.N at MS, the stride length is relatively lower compared to HS (i.e., 1.33 m and 1.45 m respectively), the stride length which is greater in HS. Likewise, we deduce that frequency increases uniformly with speed. An increase of 14.55% in speed leads to a 14% increase in the frequency of strides (i.e., from 3.5 Hz to 4 Hz). De Angelis and Menchinelli (1992) showed that at 12.65 km/h, women walkers had an average stride length and frequency of 1.01 m and 3.47 Hz, respectively, which increased to 1.09 m and 3.62 Hz at 14.1 km/h. As a result, an 11% increase in speed leads to an 8% increase in stride length and a 4% increase in frequency. You could say that walking speed is considered to be the product of stride length and frequency of movement (Koji et al., 2020).

Cairns et al. (1986), Swan et al. (1997) and Koji et al. (2020) showed that the lengthening of the stride length is maximized at the point of losing visible contact with ground by an increase in speed and relatively in frequency. Hoga, Ae, Enomoto, and Fujii. (2002) consolidated this idea and found a correlation between speed and stride length, and also between speed and frequency.

Likewise, contact time is considered to be a determining parameter of performance in walking athletes. Our results show that the C.N contact time is 0.23 s at 13.2 km/h and decreases by 0.03 s (the equivalent of 15%) with the increase in speed to 15.12 km/h. Also, we noted that the C.N values are lower than those presented by Cairns et al. (1986) who showed that at a 13.07 km/h the contact time is equal to 0.34 s. Knicker and Loch (1990) revealed that the average contact times were 0.27 s and can be influenced by the effect of fatigue which affects the kinematics of walking. Also, Bej (2020) reported a contact time equivalent to 0.33 s for 14.03 km/h walking speed.

During landing phase, the knee is the most important joint to be measured and evaluated during the competition because the rules require that the leg must be fully extended from the first contact with the ground

until it is in a vertical position. However, the judgment is entirely subjective, and therefore the definition of this rule and its implementation are not without controversy (Caporaso et al., 2019; Di Gironimo et al., 2017; Taborri, Palermo, & Rossi, 2019; Osterhoudt, 2000; Westerfield, 2007). This is because the complexity of the knee joint movements during a dynamic stride (Lafortune, Cavanagh, Sommer, & Kalenak, 1992), and the different interpretation of the extension leg definition when passing vertically of the body (Koji et al., 2020; Westerfield, 2007).

Furthermore, the results showed that during first contact with the ground, until passing to the vertical position, the angle of the knee was equal to 180° during the two speeds (i.e., 180.02° at 13.2 km/h and 180.01° at 15.12 km/h), this proves that whatever the speed of walking race, a complete extension of the support leg is essential in order to ensure an effective push to progress forward (Koji et al., 2020). Similarly, the results of Zhang and Cai (2000) showed that the average knee angle was $181^\circ (\pm 2^\circ)$ at initial contact among elite Chinese walkers. Likewise, Bej (2020) reported a knee average angle of $181^\circ (\pm 2.11^\circ)$ in women racewalker. Also, Villa (1990) confirms that the current rule is that athletes must extend their knee completely from the time of initial contact, until the end of the terminal swing.

In addition, the propulsion phase must be really active, for this it is necessary to feel the dynamic action of toes. For a wide and flexible movement, toes should be pointed in the direction of ground until they pass in front of the supporting leg. Swinging movements of the knee are also important for elite race walker, by reducing the leg moment of inertia and preparing it for full knee extension at first contact, they require less effort (Koji et al., 2020; Sovenco and Danilyuk, 2017; Villa, 1990). Levine, Richards, and Whittle (2012) demonstrated that the function of oscillation phase is to allow rear foot to clear ground and to be repositioned before the COM, ready for initial contact.

During the swing phase the C.N average knee angle is 84.09° at MS and increases to 85.01° at HS. These results showed that C.N bends his knee more significantly at different speeds compared to other athletes. Knicker & Loch (1990) measured the angle of the knee during the swing phase in five race walkers and showed a range between 87° and 108° . Also, Hanley (2014) have reported a knee angle of $100^\circ (\pm 5^\circ)$ in elite women Junior race walkers at 11.6 km/h.

Finally, the COM positioning, in relation to the ground supports and the vertical displacement, has a direct effect on the power and performance (Koji et al., 2020). The results reveal that the COM vertical displacement at different speeds is almost identical (i.e., MS = 0.064 m and HS = 0.063 m). The athlete has retained the same technique, even during speed increase, due to the high technical requirements and severe race rules to avoid risk of disqualification. By cons, Murray, Guten, Mollinger, and Gardner (1983) found that the COM vertical displacement, of two national level walkers, decreased by 0.041 m when walking quickly.

Conclusions

This kinematic study of multi-speed race-walking has shown that there is a change in the studied parameters during the transition from moderate-speed to high-speed (i.e., 13.2 km/h and 15.12 km/h). This change is remarkable for contact time (i.e., 0.23 s and 0.2 s, respectively with $\Delta = -13.04\%$), stride length (i.e., 1.33 m and 1.45 m, respectively with $\Delta = 9.02\%$) and stride frequency (i.e., 3.5 Hz and 4 Hz, respectively with $\Delta = 14.29\%$). Thus, the lengthening of the stride length is maximized by the loss of visible contact with the ground and the increase in speed and frequency. Although, this change is minimal for COM vertical displacement (i.e., 0.064 m and 0.063 m, respectively with $\Delta = -1.56\%$) and knee angle in flexion (i.e., 84.09° and 85.01° , respectively with $\Delta = 1.09\%$) and in extension (i.e., 180.02° and 180.01° , respectively with $\Delta = 0.00\%$) however, the athlete showed a high technical stability.

Since the rules of race-walking penalize a visible loss of contact with the ground, coaches and athletes should avoid changing race-walking technic/style, when changing/increasing speed. Athlete must maintain a low COM vertical displacement, full knee extension and shorter flight phase.

In summary, the lack of specific literature and knowledge of the biomechanical principles of race walking is a limiting factor for this event. More advanced studies would be very useful to determine key parameters of race-walking technique, for coaches in order to know and analyze motion characteristics as well as for athletes to optimise their performance.

Conflicts of interest

Authors declare no conflict of interest.

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