Original Research

Comparisons between Swing Phase Characteristics of Race Walkers and Distance Runners

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ABSTRACT

International Journal of Exercise Science 6(4) : 269-277, 2013. The aim of this study was to analyze swing characteristics during race walking and to compare these with distance running. 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 swing and what consequences might arise. Ten male race walkers and ten male distance runners walked or ran respectively on an instrumented treadmill for 10 km with two in-dwelling force plates. Trials lasted 30 seconds and simultaneous 2D video data were recorded and digitized at 125 Hz. The moment of inertia of the thigh, shank, foot and whole lower limb was calculated using the parallel axis theorem. The distance runners were faster with longer strides, although cadence was not different. The race walkers had shorter swing times, longer contact times, and smaller maximum knee flexion angles (100° ± 6) 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 or 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.

KEY WORDS: Elite athletes, gait, knee joint, moment of inertia, track

INTRODUCTION

Race walking and distance running form part of the athletics program in the Olympic Games and all major athletics championships. Unlike distance running, which it resembles physiologically (1), race walking is an abnormal form of gait with rules that dictate that no visible loss of contact should occur and that the knee should be straightened from first contact with the ground until the 'vertical upright position' (19). Because of the implications of this rule, previous research in race walking has focussed on the knee's movement during the stance phase (5,8,14) rather than during swing. However, the swing phase might also be affected by the rules of race walking, thereby having an influence on key kinematic variables such as stride length and making it different from distance running technique.

Walking (or running) speed is the product of stride length and cadence. Stride lengths are considerably greater in competitive distance running because race walkers are not permitted a visible flight period while by contrast there are no restrictions on a runner's technique. Whereas stride lengths between 3.22 and 3.66 m have been recorded in competitive distance running (9,15,30), the stride lengths of even the world's best race walkers only range between 2.12 and 2.38 m (women) and between 2.44 and 2.72 m (men) (13). However, distance runners and race walkers have similar cadences ranging between 1.50 and 1.65 Hz (4,5,13,15,21,30). Because their cadences (and therefore gait cycle durations) are similar, a comparison of the components of cadence (such as swing time and flight time) can aid an understanding of the effects of the restrictions on race walking gait that do not apply to distance running. Comparing race walking with a well-understood gait such as distance running could be helpful in understanding the unique and abnormal gait of race walking, which might be more difficult to achieve if analyzed in isolation.

The swing phase in gait occurs when the leg is moving through the air. Novacheck (26) stated that the purpose of the swing phase is to reposition the leg from the instant of toe-off to initial contact. In a running gait cycle there is always a flight period when both legs are at different stages of their swing phases (25) and typical swing times contribute between 64 and 78% of a running gait cycle's duration, dependent on speed (22,25). By contrast, Murray et al. (24) found that the stance:swing ratio in two male race walkers was 51:49 and 50:50 respectively, although slightly higher swing proportions of 53% (women) and 55% (men) have been reported in much larger samples of elite international competitors (14). With regard to the swing proportions in race walking, it is worth noting that although the rules stipulate that no visible flight time is permitted within race walking, research has found that very brief flight times (up to 0.04 s) do frequently occur (5,14).

The swing phase is influenced by a number of variables, including joint angles and inertial properties of the segments (23). Knee flexion during the swing phase reduces the moment of inertia (MOI) of the lower limb (3) and greater knee flexion is a characteristic of fast running (10). This is because a reduction in MOI facilitates a faster and more efficient swing phase that increases cadence and speed (25). However, race walking is different from running because of the straightened knee rule that makes it critical for race walkers to fully extend their knee toward the end of terminal swing. It is possible that this requirement means the race walker must avoid flexing the knee to an extent that a rapid reversal to full extension by initial contact could be problematic (due to the requirement for a high angular velocity of the knee during late swing that might lead to injury (6)). Furthermore, from a coaching viewpoint Villa (29) recommended not raising the foot too high during swing (instead keeping it close to the ground) so that it could return to the ground quicker and reduce the possibility of a visible loss of contact. A small number of studies have reported the maximum knee flexion angle during swing in race walking (5,20,32) with a range found between 87 and 108° (where the knee sagittal plane angle is considered to be 180° in the anatomical position). By comparison, measurements of the same variable in distance running ranged between 47 and 57° in overground and treadmill tests of 11 athletes (30).

The endurance events at major athletics competitions include both race walking and distance running. Although both are forms of bipedal locomotion, the rules of race walking make it a distinct form of gait where the athletes cannot take advantage of some features of running technique. The straightened knee rule in race walking only applies during the stance phase, but it is possible knee kinematics during swing are also affected. While the knee swing angle in race walking has been measured in some earlier studies, its importance has not been established with regard to key performance parameters such as speed and stride length and further research is therefore warranted. The aim of this study was to analyze swing characteristics of the lower limb during race walking and to compare these with distance running. It was hypothesized that due to the rule of race walking, that (i) race walkers would experience less knee flexion during swing compared with distance runners, and therefore have greater lower limb moments of inertia; (ii) that race walkers would have shorter strides and shorter swing times compared with distance runners; and (iii) that smaller leg moments of inertia would correlate with running speed and cadence.

METHODS

Participants

Ten male race walkers and ten male distance runners gave informed consent and the study was approved by the faculty's Research Ethics Committee. The race walkers' mean stature was 1.83 m (± 0.07) and mass 69.0 kg (± 9.3) and the distance runners' mean stature was 1.80 m (± 0.07) and mass 66.6 kg (± 5.4). Both sets of athletes took part in senior competition (national and international level) and their personal best times for 10 km ranged from 30 to 35 minutes (distance runners) and from 41 to 45 minutes (race walkers). The athletes normally competed over a range of distances, from 5 km to 50 km.

Protocol

Each athlete either race walked or ran on an instrumented treadmill for 10 km (h/p/cosmos, Gaitway, Traunstein) at a pace equivalent to 103% of their season's best time (e.g. a runner whose personal best for 10 km was 30 minutes would complete the test 10 km in 30:54). The race walkers were monitored by experienced international coaches to ensure they were complying with the rules. The treadmill belt was kept at a constant speed for the duration of each test. The treadmill incorporated two in-dwelling piezoelectric force plates (Kistler, Winterthur) that recorded the position of the center of pressure (COP); the COP measurements were combined by the software with measurements of the belt's movements to allow stride length to be measured. After a 10-minute warm-up and familiarisation period on the treadmill (all participants were used to training on treadmills), data were recorded at 1000 Hz for a period of 30 s after approximately 2 km. Two-dimensional video data were simultaneously collected at 250 Hz using a high-speed camera (RedLake, San Diego). The shutter speed was 1/500 s, the *f*-stop was 2.0, and there was no gain. The camera was placed 5.3 m from and perpendicular to the treadmill. The resolution of the camera was 1280 x 1024 pixels. Extra illumination was provided by two 1250 W lights placed at the side of the camera. Two 3 m high reference poles were placed one meter apart in the center of the camera's field of view in the center of the treadmill and used later for calibration (up to a height of 2 m). The experimental set-up was maintained throughout testing and participants were not made aware of when data collection occurred to avoid any conscious changes to gait.

The video files were resampled at 125 Hz and manually digitized by a single experienced operator (more than 350 video sequences digitized in published research) to obtain kinematic data using motion analysis software (SIMI Motion, Munich). The motion of the right leg of each athlete was digitized on one occasion, during the first entire gait cycle to be completely visible. The digitized points were the joint axis centers of the hip, knee, ankle, heel and the foot-tip. Identification was based on superficial bony landmarks that had markers placed on them during testing. Each video was first digitized frame by frame and adjustments were made as necessary using the points over frame method (2). The magnification tool in SIMI Motion was set at 400% to aid identification of the markers placed on the body landmarks. Digitizing was started at least 10 frames before the beginning of the stride and completed at least 10 frames after to provide padding during filtering (27). Kinematic data were filtered using a recursive second-order low-pass Butterworth digital filter (zero phase-lag) of 10 Hz (26).

De Leva's (7) body segment parameter model for men was used to obtain center of mass data for the right thigh, right shank, and right foot. These data, along with the joint coordinate data, were used to calculate the MOI of the thigh, shank, foot and total lower limb using the parallel axis theorem (31). Mass and inertial properties for the thigh, shank and foot segment were taken from de Leva (7). The radius of gyration data for each segment were taken from Winter (31). Thigh, shank, foot and whole lower limb MOI values were reported in $kg \cdot m^2$, and in addition the MOI of the total lower limb was normalized for each participant by dividing by body mass and leg length squared (17). The smallest MOI value found during swing has been described as the minimum MOI. Each athlete's full swing MOI data were interpolated to 101 points using a cubic spline (28). Stride length was measured as the distance between successive right foot contacts (toe-off to toe-off). Cadence was calculated as the reciprocal of stride time. The knee angle was calculated as the sagittal plane angle between the thigh and shank segments. The knee was considered to be 180° in the anatomical standing position, and the smallest knee angle measured during swing has been described as the maximum knee flexion angle.

Statistical Analysis
All statistical analyses were conducted using PASW Statistics 18 (IBM SPSS, Inc., Chicago, IL). Independent *t*-tests were conducted to compare values between race walkers and distance runners, with adjustments made if Levene's test for equality of variances was less than 0.05. To help reduce the chances of a type I error, an alpha level of 1% was set. Pearson's product moment correlation coefficient was used to find associations between gait variables, and only those correlations greater than 0.7 were included in this study.

Table 1. Means ± SD and between-subjects effects of key variables.

	Race walkers	**Distance runners**	t_{18}	p
Speed (m/s)	3.53 (± .18)	4.91 (± .16)	17.84	< 0.001
Stride length (m)	2.29 (± .10)	3.25 (± .23)	11.95	< 0.001
Cadence (Hz)	1.53 (± .05)	1.52 (± .09)	0.35	0.727
Swing time (s)	0.36 (± .01)	0.45 (± .03)	8.90	< 0.001
Contact time (s)	0.29 (± .02)	0.18 (± .02)	10.29	< 0.001
Flight time (s)	0.04 (± .01)	0.15 (± .01)	21.69	< 0.001
Knee angle				
Toe-off (°)	152 (± 8)	161 (± 5)	3.31	0.004
Maximum flexion (°)	100 (± 6)	56 (± 6)	16.75	< 0.001
Initial contact (°)	181 (± 3)	158 (± 5)	13.22	< 0.001
Minimum MOI				
Lower limb (kg·m^2)	1.53 (± .29)	1.20 (± .34)	2.35	0.030
Lower limb (norm)	0.033 (± .002)	0.023 (± .003)	8.98	< 0.001

RESULTS

There was no difference between the groups for stature (t_{18} = 1.04, p = .314) or mass (t_{18} = 0.70, p = .492). The values for the key variables measured in the study are shown in Table 1. The race walkers' mean swing time of 0.36 s (± 0.01) represented 55.8% (± 1.8) of their total stride time, while the distance runners' swing time of 0.45 s (± 0.03) represented 71.4% (± 2.2) of their total stride time. This difference was significant (t_{18} = 17.42, p < 0.001). In the distance running group, stride length was correlated positively with swing time (r = .70, p = 0.024) but negatively with cadence (r = –0.88, p = 0.001), and swing time was also negatively correlated with cadence (r = –0.87, p = 0.001). In the race walking group speed was correlated with stride length (r = .75, p = 0.013).

Figure 1 shows the averaged normalized MOI values during swing for both groups. The race walkers had a larger mean minimum MOI value than the distance runners when expressed as normalized values (Table 1). In the race walkers, the minimum MOI for the lower limb combined the values for the thigh (0.37 kg·m² ± 0.07), shank (0.67 kg·m² ± 0.14) and foot (0.48 kg·m² ± 0.09). The mean contributions of each segment to the total lower limb minimum MOI were therefore 24.2, 43.8 and 31.3%. In the distance runners, the corresponding values were 0.47 kg·m² (± 0.13) for the thigh, 0.46 kg·m² (± 0.14) for the shank and 0.26 kg·m² (± 0.07) for the foot. The mean contributions of each segment to the total lower limb minimum MOI in this group were 39.3, 38.4 and 21.8%. When normalized, there was no difference between groups for the minimum values for MOI of the thigh (t_{18} = 1.15, p = 0.265), although race walkers had higher minimum MOI values for the shank (t_{18} = 10.32, p < 0.001) and foot (t_{18} = 17.67, p < 0.001).

In the race walkers, maximum knee flexion angle was correlated positively with minimum normalized lower limb MOI (r = 0.78, p = 0.008) and negatively with both flight time and swing time percentage (r = –0.71, p = 0.023 and r = –0.72, p = 0.020 respectively). No significant correlations were found between either maximum knee flexion angle or normalized MOI with speed or swing time. In the distance runners, maximum knee flexion angle was similarly correlated positively with minimum normalized lower limb MOI (r = 0.80, p = 0.005) but once again no correlations were found with key performance parameters such as stride length and cadence.

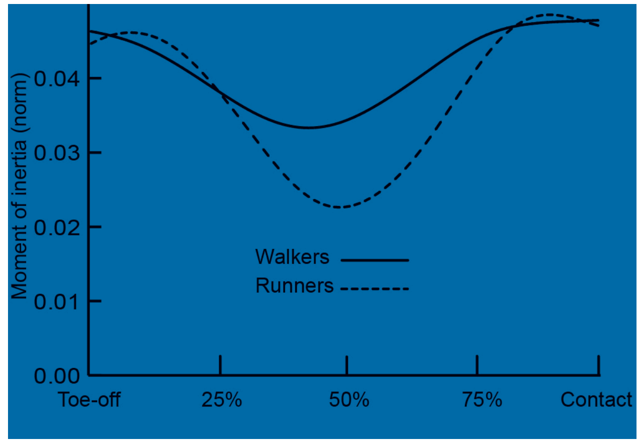

Figure 1. Average normalized moment of inertia values during swing for both race walkers and distance runners.

DISCUSSION

The aim of this study was to analyze swing characteristics of the lower limb during race walking and to compare these with distance running. From the point of view of kinematic performance parameters, the distance runners in this study were faster than the race walkers due to their longer stride lengths. Mean cadence was not different although the proportion of time spent in swing was greater in the distance runners, and the longer stride lengths in the distance runners were associated with longer flight times. The race walkers' much shorter mean flight times were expected because of the requirement for the race walkers to adopt a technique that avoided a visible loss of contact.

The smaller mean range that the knee flexed through following toe-off for the race walkers (from 152° to 100°) compared with the distance runners (from 161° to 56°) meant that the race walkers' knees reached a much smaller maximum knee flexion angle during midswing. In addition, the race walkers' average knee angle of 181° (± 3) at initial contact was larger than that of the distance runners and these figures suggest that the race walkers prevented knee flexion from reaching the magnitudes achieved by the runners so that full knee extension by initial contact was facilitated. Maintaining this range of motion for every stride during a walking race (Olympic distances are 20 km and 50 km) (14,16) requires appropriate strength endurance and mobility, particularly in the last quarter of the 50 km race where technique tends to break down with subsequent decreases in pace (16). In addition, appropriate training needs to consider the potential for injury to key knee muscles such as the hamstrings (which are frequently injured in race walking (11)) due to peak stretch and negative work demands during swing (6).

The knee flexion angles and swing time proportions were similar to those found in previous research on race walking (5,14,20,32) and distance running (22,25,30). In the race walking group, the correlation between maximum knee flexion angle and minimum MOI showed that the negative effect of the technique adopted was a greater inertial resistance to swing. However, the lack of any association with speed or either of its components suggests that swing MOI might not be a critical factor in success and in terms of being competitive in race walking, maintaining a technique that facilitates knee extension at heel-strike is more important. In addition, restricting the amount of knee flexion during swing might also be important in maintaining very short and undetected flight times, as maximum knee flexion and swing time percentage were both positively correlated with flight time. The coaching recommendation that race walkers avoid too much knee flexion so that full knee extension is achieved at initial contact (29) is supported by this study's results as the potential negative consequences (i.e. disqualification) are not outweighed by any benefits to speed. The recommended technique might not be easily achieved because of its abnormal pattern compared with running; athletes must be patient in developing optimal techniques with appropriate training programs (12,18) and coaches should monitor their development closely.

The race walkers had greater MOI values for the whole lower limb, shank, and foot than the distance runners. The greater knee flexion angle during the running motion meant that the distal segments of the lower limb were closer to the hip axis during midswing and meant that the foot only contributed 21.8% of the lower limb minimum MOI compared with 31.3% in the race walkers. As in race walking, more acute knee flexion angles were associated with lower MOI values of the lower limb during distance running. The rules of race walking make it a stereotyped form of gait (8) whereas distance runners are not under similar constraints and so their varied stride lengths and cadences might have been a cause of the lack of associations between MOI values and key performance variables.

The movement of the lower limb during the swing phase is an important component of successful competitive gait and particularly for race walkers who must obey two specific rules. The rules of race walking do not just affect the knee angle during stance, but also during swing because of the need for full knee extension prior to heel-strike and in avoiding a visible loss of contact. Athletes and coaches involved in race walking need to be mindful of the need for appropriate technical development in line with strength and endurance requirements.

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