GAIT ALTERATIONS DURING CONSTANT PACE TREADMILL RACEWALKING

Running head: Altered gait during treadmill racewalking

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ABSTRACT

Racewalking is an Olympic event requiring great endurance, and racewalkers often use treadmills in training because of the benefits of having a flat, unchanging surface where pace judgment can be learned, and because inclement weather can be avoided. The effects of fatigue associated with racewalking on a treadmill have not been studied, and could be informative with regard to the maintenance of legal technique. The aim of this study was to measure key gait variables during a physically demanding treadmill racewalk. Fourteen international racewalkers completed 10 km on an instrumented treadmill at a pace equivalent to 103% of their recent best time. Spatiotemporal and ground reaction force data were recorded at four distances. High-speed videography data were simultaneously recorded to analyze changes in knee angle between the early and late stages. Increases in step length and corresponding decreases in cadence were found, although the small changes were not considered meaningful. There was also a small increase in flight time and a small decrease in push-off force. There were no other significant changes for any other variables (including knee angles). The increase in flight time might be important given that racewalkers are not permitted a visible loss of contact and suggests that fatiguing sessions on a treadmill can lead to the adoption of non-legal technique. However, this disadvantage of treadmill training can be negated if the coach scrutinizes the athlete throughout the session, and overall the consistent technique used is of benefit with regard to learning correct form and pacing ability.

Key words: biomechanics; coaching; endurance; fatigue; pacing; track and field.

INTRODUCTION

Racewalking is an Olympic event within the track and field program defined as a progression of steps so taken that no visible (to the human eye) loss of contact with the ground occurs and the leg must be straightened from first contact with the ground until the ‘vertical upright position’ (Rule 230.1) (16). As an endurance event, previous research has shown how the maintenance of key spatiotemporal variables such as step length and cadence despite fatigue is a critical aspect of world-class performances (11,12), and thus any conditioning work that can help maintain these and other gait variables (e.g. stride width (21)) is crucial. In addition, adopting an even pacing profile is a key skill used by elite racewalkers in major championships (10) and should be learned before competing. One method that might be useful with regard to both of these key elements is to racewalk on a treadmill moving at a relatively fast but constant speed in training.

Unlike running competitions, it is stipulated that racewalking events should be held over repeated loops (between 1 and 2 km in distance) where a level, unchanging surface is required (16). It is therefore possible that the nature of treadmill training is even more suitable for racewalkers than for distance runners, and indeed could be an indispensable component of their training. Benefits other than the ability to maintain a constant fast pace include easier access to drinks or energy gels, the facility for coaches to watch for technical weaknesses or rule infringements, and the avoidance of adverse weather (or the achievement of specific conditions in an environmental chamber, for instance) that reduces extraneous factors when testing (22). Treadmills have also proven useful for analysis of racewalking biomechanics over relatively short durations (23) and in finding increases in energy cost after a long overground training session (4). While these studies also examined a number of kinematic parameters, underlying kinetic variables such as vertical ground reaction forces

(GRF) are also important to consider in any form of gait (19). In this regard, instrumented treadmills (i.e. with in-built force plates) were shown to be very valuable in comparing spatiotemporal variables between racewalking and distance running (30) and should also be useful in evaluating any important biomechanical changes in racewalkers due to fatigue.

Because racewalking technique is judged by the human eye, very brief but non-visible flight phases are normal in world-class competition (11-13). The subjectivity involved in judging means that there is no exact threshold above which flight is seen, although loss of contact lasting less than 40 ms is typically undetected by judges (6,18). Previous research on fast, constant-paced treadmill running over 10 km showed an increase in flight time with distance (14), and while this might not be unduly worrying for an endurance runner, it would obviously be of concern to the elite racewalker. Furthermore, small changes in initial contact knee angles were found in fatigued distance runners (14), and it is therefore possible that the similar usage of a treadmill by racewalkers could encourage the adoption of ‘bad habits’ in the form of non-legal technique. However, as other important gait parameters remained largely unchanged during treadmill distance running (14), there clearly are potential gains for the elite racewalker who adopts treadmill training with regard to the maintenance of consistent technique, although these benefits and any possible disadvantages have not yet been studied.

Treadmill training over long distances is frequently used by racewalkers who require a flat, unchanging surface where unfavorable conditions can be avoided. Knowledge of whether important gait parameters change with fatigue on a constant speed treadmill and to what extent will be useful to racewalkers and their coaches, and will be particularly important for those who compete at world-class competitions and are scrutinized by highly qualified judges. For the strength and conditioning professional, the practical value of this study is that it will highlight potential advantages and disadvantages of using treadmills, not only for racewalkers but for other athletes. This will be useful when prescribing endurance training sessions on treadmills that can also be used for identifying and monitoring technical strengths and weaknesses. The aim of this study was to measure key gait variables during the course of a 10 km treadmill racewalk. It was hypothesized that GRF and spatiotemporal variables would change because of fatigue induced by the physically demanding nature of the test protocol.

METHODS

Experimental Approach to the Problem

A within-subjects repeated measures design was used to assess changes in racewalking gait parameters during a fast 10 km racewalk on an instrumented treadmill. Subjects attended the laboratory on a single occasion and racewalked at a pace close to their most recent best performance. Key gait variables were measured using in-dwelling force plates and high-speed video analysis. The treadmill belt was kept at a constant speed in order to measure changes in these variables due to distance racewalked rather than due to changes in pace.

Subjects

Fourteen international racewalkers participated in the study, of whom nine were men (age: 30.4 ± 7.7 years, height: 1.82 ± .07 m, mass: 71.9 ± 7.2 kg) and five were women (age: 22.2 ± 3.8 years, height: 1.67 ± .04 m, mass: 53.0 ± 8.1 kg). The athletes frequently compete over the standard championship distances of 20 km (men and women) and 50 km (men only) as well as shorter distances. Eight athletes had competed at the Olympic Games or World Championships, while the others had competed at the IAAF World Race Walking Cup. The

Faculty Research Ethics Committee approved the details of the study including consent documentation and information to subjects before commencement. In accordance with the Institutional Review Board's policies for use of human subjects in research, all subjects were informed of the benefits and possible risks association with participation, and informed of their right to withdraw at any point. All subjects were over the age of 18 and gave written informed consent to indicate their voluntary participation.

Procedures

After a 10-minute warm-up and familiarization period (20), each subject racewalked for 10 km on a treadmill (Gaitway, Traunstein) at a pace equivalent to 103% of their recent 10 or 20 km race pace (i.e. within the previous two months). This pace was chosen based on prior similar research (14) and because it was felt that it would achieve a fatigued state while not being so fast that the athletes could not complete the test (especially considering the non-competitive nature of testing). The mean treadmill speed during testing was 12.37 $km \cdot h^{-1}$ (± 0.77) and each athlete racewalked at a constant pace for the duration of the test. The treadmill's inclination was set at 0% during data collection (1,32) as racewalking events are held on flat, even surfaces. Subjects wore their normal training clothing and footwear for indoor training sessions, and as all subjects were from northern European nations (e.g. Finland, Sweden) where winter weather conditions make outdoor training difficult, all were frequent and experienced users of treadmills in training. The treadmill incorporated two in-dwelling piezoelectric force plates (Kistler, Winterthur) that recorded vertical GRFs (1000 Hz) from both feet as well as temporal data. The force plates also recorded the position of the center of pressure (COP) from which step length and stride width were measured. Data were collected for 30 s on four occasions, beginning at a calculated time that resulted in the midpoint of data collection occurring at 2500 m, 4500 m, 6500 m and 8500 m of total distance racewalked. Approximately 90 steps were recorded during each of these 30-s data collection periods and the data averaged before analysis. The Rate of Perceived Exertion Scale (RPE) (3) was used to measure self-ratings of fatigue on a scale of 6 – 20 (e.g. a score of 11 represented a ‘fairly light’ rating, and 15 represented a ‘hard’ rating). The treadmill control panel was concealed during testing to prevent the athletes from being distracted or knowing when testing was taking place (26); however, they were informed when they reached each successive kilometer (similar to race conditions). A fan was placed in front of the subjects to help cool them, and bottled water was available on request.

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 each side of the camera. Before each testing session, two 3 m high reference poles were placed in the center of the camera’s field of view in the center of the treadmill and later used for calibration. The movements of the lower limbs over the course of one stride during the first and last recordings (2500 m and 8500 m) were analyzed. The video files were manually digitized by a single experienced operator to obtain kinematic data using motion analysis software (SIMI Motion 8.5.6, Munich). Each video was digitized frame by frame and adjustments were then made as necessary using the points over frame method (2). The magnification tool in the software was set at 400% to aid identification of 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 (31). Dropout occurred on the left hand side of the body on some occasions and estimations were made by the operator. The kinematic data were filtered using a recursive second-order low-pass

Butterworth digital filter (zero phase-lag) of 10 Hz. Knee joint angular data were derived from digitized body landmarks. A single stride was chosen for analysis because of time constraints and the low variability in knee angular motion during the highly stereotyped racewalking gait (7).

Step length was defined as the distance from one foot strike to the next foot strike of the opposite foot. Contact time was defined as the time duration from initial contact to toe-off, whereas flight time was the time duration from toe-off of one foot to the initial contact of the opposite foot (24). Step time was calculated as the sum of contact and flight time, while cadence was calculated as the reciprocal of step time. Stride width (also known as base of support) (19) was defined as the mean distance between a foot's mediolateral COP and the next opposing foot's mediolateral COP for each foot strike. The knee angle was calculated as the sagittal plane angle between the thigh and leg segments and was considered to be 180° in the anatomical standing position (24). Knee joint angles have been presented in this study at initial contact and the ‘vertical upright position’ (16); initial contact was defined as the first visible point during stance where the athlete’s foot clearly contacts the ground, while the vertical upright position was defined as the instant when the athlete’s foot was directly below their hip joint (using their respective horizontal coordinates).

The vertical GRF data variables analyzed were impact peak force, loading peak force, midstance force, push-off peak force, and push-off rate. The impact peak was defined as the highest recorded force during the first 70 ms of contact. The loading peak force was identified as the next peak in the vertical GRF trace during early stance, whereas the midstance force value was measured as the minimum force occurring between the loading and push-off peaks. The push-off peak force was itself identified as the maximum vertical force during late stance, while the push-off rate was the slope of the force curve during unloading, taken from the point of 90% of push-off peak force to the point of 10%. To account for differences in body size, all GRF data were normalized and expressed as bodyweights (BW). All kinetic, kinematic and spatiotemporal variables were measured for both left and right legs and averaged for the purposes of this study.

Statistical Analyses

To measure any changes in the variables obtained using the treadmill force plates, one-way repeated measures ANOVAs were conducted with repeated contrast tests to establish significant differences between successive measurement points (8,17). An alpha level of 5% was set for these tests with Greenhouse-Geisser correction used if Mauchly's test for sphericity was violated. The effect size was reported using partial eta-squared (η_p^2) (17). The knee angle data that were obtained using the high-speed video recordings were compared using dependent *t*-tests. Effect sizes (ES) for differences between the first and last data measurements for all variables were calculated using Cohen's *d* (5) and considered to be either trivial (ES: < 0.20), small (0.21 – 0.60), moderate (0.61 – 1.20), large (1.21 – 2.00), very large (2.01 – 4.00), or nearly perfect (> 4.00) (14).

RESULTS

The values for RPE, step length, cadence, and stride width are shown in Table 1. An increase in mean step length was found to occur ($F = 11.49$, $p < 0.001$, $\eta_p^2 = .47$, power = .999), with a corresponding decrease in cadence ($F = 5.31$, $p = 0.004$, $\eta_p^2 = .29$, power = .905). However, the effect sizes found for both of these key kinematic variables were trivial (ES = 0.19 and 0.17 respectively), and no differences were found for stride width. The mean knee angle at initial contact was 181° (± 2) at 2500 m and 181° (± 3) at 8500 m, while at the vertical upright position it was 186° (± 3) at 2500 m and 184° (± 4) at 8500 m; no differences were found.

*** Table 1 about here ***

Table 2 shows the mean step time at each measurement distance, as well as its two components, contact time and flight time. In addition, the proportion of step time spent in flight is shown as flight time (%). While it was expected that there would be an increase in step time (F = 5.77, p = 0.011, η_p^2 = .31, power = .789) because of the decrease in cadence, the effect size was trivial (0.17) and no differences between successive measurements were found. Contact time did not change, but significant increases in flight time did occur (F = 9.20, p = 0.001, η_p^2 = .41, power = .961), with a small effect size of 0.35. As a result, the flight time proportion increased over the course of testing (F = 7.76, p = 0.002, η_p^2 = .37, power = .924) with a small effect size of 0.34.

*** Table 2 about here ***

Table 3 shows the results for the peak impact force, loading force, midstance force, push-off force and push-off rate. There were no changes in these values with distance racewalked except for push-off force, which decreased during testing (F = 11.31, p < 0.001, η_p^2 = .47, power = .999), although the effect size was small (0.30).

*** Table 3 about here ***

DISCUSSION

The aim of this study was to measure key gait variables during the course of a 10 km treadmill racewalk and it was hypothesized that GRF and spatiotemporal variables would change because of fatigue. However, many of the variables measured did not change, including stride width and most vertical GRF variables (the exception was push-off force). An increase in step length with a corresponding decrease in cadence was found, although these changes were trivial and therefore not meaningful alterations in gait. Instead, the small changes in their means (of .01 m and .02 Hz respectively) were indicative of normal variations (e.g. the respective standard deviations were much greater) and not necessarily induced by the test (27). Overall, it would therefore appear that elite racewalkers maintain their gait patterns over the course of a physically demanding treadmill session, as has been similarly reported for distance runners (14). This suggests that using a treadmill for constant pace training is a potentially valuable means for racewalkers to develop a consistent gait pattern with low variations in how the legs are stressed, a particularly important finding given the consistency of world-class racewalkers' spatiotemporal variables in competition (11,12) and the need to learn even pacing before racing (10).

The specific rules of racewalking make it a distinctly different gait from distance running (30) or normal walking (25) and alterations in either flight time or the knee angle at initial contact or midstance are of particular concern for racewalkers and their coaches. While this study found no change in knee angle between early and late stages, as has been found in world-class racewalkers in competition (11,12) and in 10 km distance runners using a constant pace treadmill (14), there was however an increase in flight time between 2500 m and 8500 m (to 44 ms). Although the effect size was small, this increase might nonetheless be meaningful because of the subjective nature of racewalk judging whereby loss of contact is typically detected at durations above 40 ms (18). As in fatiguing treadmill running (14), increasing flight time might be a means for tiring racewalkers to keep up with a fast-moving, constant pace treadmill belt and is the most obvious disadvantage of using this method of training (especially if they racewalk further than the 10 km covered in this study). This small increase in flight time might have been occurred because of muscle fatigue and achieved through the increase in step length that, while seemingly trivial, allowed the racewalkers to gain additional time in the air. Similar findings were found for constant pace treadmill running (14) and highlight the role that slight alterations in gait kinematics can make to keeping up with a fast moving treadmill belt. Racewalkers should therefore be cautious of using treadmills extensively in training lest it lead to the development of non-legal technique; in particular, the coach should monitor these sessions to ensure that visible loss of contact does not occur as fatigue sets in. Such an eventuality might be more common in physically demanding training sessions where the athlete is determined to complete the training racewalk within a planned time, and legal technique is sacrificed for speed.

While the key results of this study have shown that treadmill training can be very beneficial for racewalkers, there is nonetheless a need for coaches and athletes to be aware that in some studies, overground gait has been found to differ from that used on a treadmill (e.g. 29), and in particular, caution has been advised when using treadmills to test the effects of fatigue on running biomechanics (9) (which could also apply to racewalking). Along with the small increase in flight time found in this study, this potential lack of transferability between conditions means that treadmill usage should possibly be restricted to situations where outdoor training is unfeasible (e.g. if the weather is inclement). However, using a constant belt speed lessens the differences between treadmill and overground locomotion (28), while a familiarization period causes the differences to disappear (20) with the result that both forms of locomotion are essentially equivalent (27) and thus training (or testing) at a continuous fast pace can still be ecologically valid. A limitation of the instrumented treadmill used is its inability to record shear forces, and in particular the absence of measured anteroposterior forces means that any potential effects of fatigue on braking or propulsive impulses is absent. However, using the treadmill meant avoiding any potential targeting of the force plates that can often occur in overground GRF data collection, and furthermore allowed for a large sample of successive force traces to be recorded at any one time so that the effect of outliers was reduced. Further research that compares overground and treadmill racewalking will complement that already undertaken on both normal walking and running and provide racewalkers with a better understanding of the value of treadmill training.

PRACTICAL APPLICATIONS

This study of the effects of a physically demanding racewalk on a constant pace treadmill shows that while there were some gait differences with distance racewalked, their trivial or small effect sizes meant they were largely meaningless. In essence, the racewalkers withstood any effects of fatigue and maintained their gait patterns throughout. Treadmills can therefore be used by racewalkers when developing their cardiovascular and muscular endurance, as well as honing their pacing abilities, with the added advantage of easier coaching. However, this coaching benefit should not be merely considered a potential bonus but actually adopted as an integral part of any treadmill session for it permits continuous judgment of legal racewalking technique. This is particularly important for monitoring any visible loss of contact, rather than for knee infringements, given the way athletes seem to cope with fatigue by slightly increasing their flight times. It should be noted though that the athletes in this study were all elite-standard, and so the effects of fatigue could be different for less well-trained athletes whose technique is less developed, and they might need to exercise even more caution if training on a treadmill. For the strength and conditioning professional, this study adds to prior research on distance running in demonstrating the value of prescribing treadmill training for the development of consistent technique (that can be monitored and corrected) and pacing ability within a program designed to improve cardiovascular and muscular endurance.

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Table 1 RPE, step length, cadence, and stride width (mean ± SD) at each distance

Distance	RPE	Step length (m)	Cadence (Hz)	Stride width (m)
2500 m	12 ± 1	1.11 ± 0.09	3.09 ± 0.13	.037 ± .025
4500 m	13 ± 1	1.11 ± 0.08	3.08 ± 0.13	.039 ± .026
6500 m	15 ± 2	1.12 ± 0.08	3.07 ± 0.13	.037 ± .024
8500 m	16 ± 2	1.12 ± 0.09	3.07 ± 0.13	.039 ± .025

Table 2 Temporal data (mean ± SD) at each distance

Distance	Step time (s)	Contact time (s)	Flight time (s)	Flight time (%)
2500 m	.324 ± .013	.285 ± .018	.039 ± .016	12.1 ± 4.8
4500 m	.325 ± .013	.283 ± .018	.042 ± .015†	12.8 ± 4.7
6500 m	.326 ± .014	.282 ± .017	.044 ± .014†	13.4 ± 4.3†
8500 m	.326 ± .013	.282 ± .017	.044 ± .013	13.6 ± 4.1

A significant difference from the previous measurement is denoted as $p < 0.05$ (†) based on repeated measures contrasts.

Table 3 Peak force data (mean ± SD) at each distance

Distance	Impact (BW)	Loading (BW)	Midstance (BW)	Push-off (BW)	Push-off rate ($BW \cdot s^{-1}$)
2500 m	1.45 ± 0.26	1.77 ± 0.17	1.33 ± 0.30	1.56 ± 0.11	15.46 ± 3.66
4500 m	1.47 ± 0.28	1.77 ± 0.18	1.34 ± 0.30	1.56 ± 0.12	14.97 ± 3.03
6500 m	1.45 ± 0.28	1.75 ± 0.18	1.33 ± 0.30	1.54 ± 0.11	15.24 ± 3.31
8500 m	1.45 ± 0.28	1.74 ± 0.17	1.30 ± 0.29	1.53 ± 0.12†	15.00 ± 2.79

A significant difference from the previous measurement is denoted as $p < 0.05$ (†) based on repeated measures contrasts.