The effect of uphill stride manipulation on race walking gait

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ABSTRACT: Stride length analysis represents an easy method for assessing race walking kinematics. However, the stride parameters emerging from such an analysis have never been used to design a training protocol aimed at increasing stride length. With this aim, we investigated the effects of stride frequency manipulation during three weeks of uphill (2%) training on stride length at iso-efficiency speed. Twelve male race walkers were randomly allocated to one of two training groups: stride frequency manipulation (RWM, n=6) and free stride frequency (RWF, n=6). Results. Kinematic parameters measured before and after the 3-week training in RWM showed increased stride length (4.54%; p<0.0001) and contact time (4.58%; p<0.001); inversely, a decreased stride frequency (4.44%; p<0.0001) and internal work (7.09%; p<0.05) were found. In RWF the effect of the training showed a decrease in stride length (1.18%; p<0.0001) and contact time (<1%; p<0.0001) with respect to baseline conditions and an increased stride frequency and internal work of 1.19% (p<0.0001). These results suggest that using slopes (2%) as RWM could help coaches to provide some training methods that would improve an athlete's performance, through increasing stride length without altering his or her race walking technique or metabolic demands.

INTRODUCTION

Olympic race walking (RW) is an historical competition, even though only a small number of athletes participate; indeed, race walking has been investigated more often in the laboratory than during competition [1]. An increasing interest in race walking competitions can be seen in the research [2-5]. Moreover, numerous factors have been shown to influence RW performance, including metabolic demand [4,5], stride technique [2,3,6] and nutritional factors [7]. Indeed, race walkers require considerable training and preparation [8]. The importance of investigating various critical aspects involved in RW competitions [2,3], such as energy cost [9], has become evident in recent years.

In particular, researchers have taken a strong interest in training studies in order to understand how energetic cost in high level race walkers can be optimized [10,11]. Within RW races there are variations in the track terrain, in which small differences in the slope that can influence the mechanics of RW are often present [12]. During a longer competition, such as the 50 km race, top level race walkers usually take approximately 52,600 strides [6], and stride length can decrease by 4% between the start and the end of the race [3]. Therefore, increases in stride length could be advantageous,

because this would allow for the same speed to have a lower stride frequency and a better mechanical efficiency [13].

According to this hypothesis, focusing on stride parameters which change the individual stride frequency [6] is desirable in training for improving the stride length, as demonstrated in marathon runners [14]. Usually, uphill RW is used to improve race walking gait [6,13], but its chronic effects are unknown. Furthermore, it can be stated that uphill RW alone does not help to improve stride length [6]. Indeed, a recent study has shown that even at low speeds on small slopes (2%), RW energy cost increased by 0.30 J/(kg·m) [15] over the energy cost at 0%, while the stride length decreased by ~4% at both constant and low speed with respect to the level gradient [6]. Therefore, it may be useful to perform race walking on a slope at iso-efficiency speed (decreasing the velocity) [13], without increasing the metabolic demand, as well as on the level, as demonstrated in running [16], but manipulating stride frequency.

In addition, considering that during uphill RW stride length decreases [6], it is important to decrease the speed to allow race walkers to adequately modify stride parameters during uphill RW training. In the current study, we hypothesize that manipulating the

stride frequency in uphill training will prove advantageous to stride length during level RW. Therefore, the aim of this study was to investigate the effects of the stride frequency manipulation (same stride length on level gradient) vs. free stride frequency during training on a slope (2%) at iso-efficiency speed [13] in national race walkers.

MATERIALS AND METHODS

Participants. Twelve male race walkers (Senior's category) were selected for this study following the approval of the University Ethical Committee. All the subjects were randomly assigned to one [17] of the two groups: stride frequency manipulation (RWM= 6, age 24.8±7.4 years, height 1.77±0.08 m, weight 60±6.32 kg, body mass index (BMI) $19.14±0.72$ kg$\cdot$m^{-2}) and free stride frequency (RWF= 6, age 24.2±5.7 years, height 1.78±0.05 m, weight 61.85±4.74 kg, BMI 19.44±1.16 kg$\cdot$m^{-2}). The inclusion criterion was: high skill with more than six years of training (all were ranked at the national level in their category). None of the athletes suffered from nutritional disturbances, none had any musculoskeletal injuries, and no medications or drugs expected to affect their physical performance were taken during the course of this investigation.

In order to make the group homogeneous with regard to the training conditions, none of the subjects performed any strenuous endurance activity and/or resistance training outside of their normal endurance training protocol. The diet control was designed to eliminate the risk of any differences in the total consumption of proteins, carbohydrates and of saturated and unsaturated fats; all the athletes lived together and followed the recommendations of the same sports nutritionist. The TCU Institutional Review Board for the use of Human Subjects approved the details of this study, as well as all related informational and consent documentation, before any data collection was performed. After being informed of the procedures, methods, benefits and possible risks involved in the study, each subject reviewed and signed an informed consent form prior to participation in the study, in accordance with the ethical standards.

Procedures

All subjects were tested before (double check for the reliability of the measures) and after the training intervention in the Human Performance Laboratory. All the tests were carried out in a climate-controlled laboratory: average temperature 23.5°C (min 23°C, max 24°C), between 4:00 p.m. and 7:00 p.m. to control for circadian variation [18]. Riley et al. (2008) reported a high correlation ($r = 0.93$) between over-ground and treadmill walking [19]. All the subjects wore RW shoes (Category A2, 135 g) and performed a standardized 15-min warm-up, consisting of RW at 9 km$\cdot$h^{-1}, in order to familiarize themselves with the treadmill [20] (Run Race Technogym Run 500, Gambettola Italy [21]). The subjects performed 5 min of dynamic muscular stretching [22] prior to performing the treadmill test for kinematic analysis. The treadmill was calibrated and checked before and after each test, according to the instructions of the manufacturer [20]. Percent grade (%) was expressed as being equal to the

tangent [theta] × 100 [20]. The speed at "0" level (mean ± SD) for the 5-min duration was set at 1 km$\cdot$h^{-1} less than the best mean speed performed by each participant for 10,000 m (IES$_0$) corresponding to 12.83±0.60 km$\cdot$h^{-1} [13]. Previous studies have found that this corresponds to ~50% (estimate) maximal oxygen consumption (VO$_{2max}$) [23] and requires an energy cost (Cw) of 5.0 J$\cdot$(kg$\cdot$m)$^{-1}$ [9,23]. Furthermore, according to the previous data [15] the increase in Cw as a result of a level gradient is:

$$Cw_i = 0.15 \times slope_i (\%) + Cw_0 ,$$

where Cw$_0$ is the Cw at a level gradient (0%).

As mentioned above, oxygen consumption (VO$_2$) is proportional to the energetic cost and velocity, so for each gradient the velocity (IES$_i$) at which the VO$_2$ was equal to level RW was calculated by taking VO$_2$= [(Cw$_0$ / (21 (J$\cdot$min^{-1})) × ((IES$_0$ / 0.06 (m$\cdot$min^{-1})))], where 21 (J$\cdot$min^{-1}) and 0.06 (m$\cdot$min^{-1}) are constant values. This leads to the equation:

$$IES_i \ (km \cdot h^{-1}) = [(VO_2 \ (kJ/min/kg) \times 21 \ (J/l) \times 0.06 \ (m/min)) / (0.15 \times slope_i (\%) + Cw_0)].$$

Kinematic Analyses

Pre- and post-training two-dimensional (*2D*) video data of the subjects' RW on the treadmill were collected using a high-speed (210 Hz) camera (Casio Exilim FH20, Japan). In accordance with previous studies [13,14,24], considering that the treadmill device was 50 cm high, the camera was positioned on a 1.5 m high tripod standing 6 m from the participant, and was located perpendicular to the plane of motion and the participant's sagittal plane [25] as standard calibration. The film sequences were analyzed off-line using Dartfish 5.5-Pro motion analysis software (Dartfish, Fribourg, CH). The following kinematic variables were studied: (i) contact time (ms), (ii) stride length (m), and (iii) stride frequency (Hz); 100 strides were sampled [26] within the 5-min duration of the test. Stride frequency was freely chosen within the pre and post-test training. Since the velocity of the treadmill was known, both stride length (left/right, SL) and stride frequency (SF) could be calculated. The contact time (CT) was calculated for both the left and the right foot [27].

The CT was defined and calculated as the time between initial contact (rear foot) with the ground and the last frame of contact before toe-off (forefoot). Initial contact and toe-off were visually detected. According to previous studies [6,13,16,28], SF was calculated as SF= [1000/CT)]; alternatively, SL was calculated with the following equation: SL= [(speed/3.6)/SF].

Internal Work

We calculated the internal work (W$_{INT}$) with the Nardello equation [29]

$$W_{INT} = SF \cdot v \cdot (1 + (DF \cdot (1 - DF)^{-1})^2) \cdot q ,$$

where SF is the stride frequency (Hz), *v* is the speed (m$\cdot$s^{-1}), DF is the duty factor – i.e. deflection of the duration of stride period when each foot is on the ground (%) and *q* the value of 0.1 referring to the inertial properties of the oscillating limbs.

Training on a Slope

Slope training was carried out on the treadmill (Run Race Technogym Run 500, Gambettola Italy) over three weeks, with two training sessions per week (Monday and Friday), in accordance with a previous study [14]. All the participants wore RW shoes (Category A2) and performed a standardized 15-min warm-up, consisting of RW at 9 km·h⁻¹ on a treadmill at a level gradient and following 3 min of RW on a 2% slope before each set.

The RWM group performed the following training procedure on the treadmill: 5 sets of 5-min RW at a 2% gradient at IES (IES$_2$) with a manipulated individualized stride frequency. Between each set 5 min of active recovery was performed, which consisted of RW at 0% gradient and speed corresponding to IES$_2$ minus 1.5 km·h⁻¹. IES$_2$ and stride frequency were 12.08±0.59 km·h⁻¹ and 3.07±0.25 Hz, respectively. Manipulated stride frequency on a slope was predetermined. SF was calculated in order to replicate the same stride length elicited during level RW at IES, in accordance with the training equation [6]. The athletes were requested to count their strides and to replicate the number each minute (visual counter each 30 s with treadmill display, with an error of one stride).

Training equation for slope= [(speed (km·h⁻¹) / 3.6 (m·s⁻¹)) during slope / SL (m) during level × 60 (min)] [6].

The RWF group performed the following training procedure on the treadmill: 5 sets of 5-min RW at 2% gradient at IES$_2$ with a freely chosen stride frequency. IES$_2$ and stride frequency were 12.13±0.58 km·h⁻¹ and 2.92±0.15 Hz, respectively. Between each set, 5 min of active recovery was performed, which consisted of RW at 0% gradient and speed corresponding to IES$_2$ minus 1.5 km·h⁻¹. To balance the training load, both groups (RWM-RWF) during the training weeks (4 days per week) performed the same normal training programme on a level gradient (based on ~14.5 km per day).

Statistical Analysis

Data are reported as mean ± SD. The kinematic variables (i) contact time, (ii) stride length, (iii) stride frequency and (iv) internal work were analysed using a separated two-way ANOVA with repeated measures and Bonferroni post-hoc tests. The effect size (η^2) was calculated for all variables between pre- and post-testing. For testing the repeatability of the measure [30], we first calculated the intraclass correlation coefficient (ICC) for each variable measured. Assumption of normality was verified using the Shapiro-Wilk W. Test. The within factor was time with two levels (pre- and post-training) and the between factor was the training with at two levels (RWM and RWF). Furthermore, a t-test was used to compare pre- and post-training in different groups for: (i) contact time, (ii) stride length, and (iii) stride frequency. Then, a pair-wise comparison was performed when the main effect was significant, and the significance level was set at p < 0.05. Statistical analysis was performed using SigmaPlot software 11.0 (Systat Software, Tulsa, OK).

RESULTS

There were no differences between the two groups at baseline conditions for age, height, weight, training experience or RW velocity on both the level and a slope (2%). The test-retest reliability of this testing procedure was demonstrated through an ICC and standard error of measurements (SEM) for the following variables: stride length (ICC: 0.97–0.98, SEM: 0.03–0.07 m), contact time (ICC: 0.96–0.98, SEM: 9–11 ms) and stride frequency (ICC: 0.95–0.98, SEM: 0.8–0.11 Hz).

Repeated measures ANOVA showed significant differences between the two training groups in CT: $F_{(1,10)}= 32.856$, p < 0.0001 ($\eta^2= 0.767$) and the interaction training type × time $F_{(1,10)}= 94.776$, p < 0.0001 ($\eta^2= 0.905$). Significant differences were also found for SF: $F_{(1,10)}= 24.038$, p < 0.001 ($\eta^2= 0.706$) and the interaction training type × time $F_{(1,10)}= 71.022$, p < 0.0001 ($\eta^2= 0.877$). Similarly, significant differences were found for the SL: $F_{(1,10)}= 40.941$, p < 0.0001 ($\eta^2= 0.804$) and the interaction training type × time $F_{(1,10)}= 120.115$, p < 0.0001 ($\eta^2= 0.923$). W_{INT} showed significant differences: $F_{(1,10)}= 5.784$, p = 0.037 ($\eta^2= 0.584$) and the interaction training type × time $F_{(1,10)}= 11.372$, p = 0.007 ($\eta^2= 0.859$).

TABLE I. Effects of uphill race walking training on step analysis.

	BASELINE	RWM	RWF
Contact time (ms)	311 ± 16.89	324 ± 22.96*	308 ± 7.56†
Step frequency (Hz)	3.23 ± 0.18	3.10 ± 0.23†	3.25 ± 0.08†
Stride length (m)	1.11 ± 0.09	1.15 ± 0.12†	1.10 ± 0.07†

Note: Kinematic variables in the step frequency manipulation group (RWM) and the free step frequency group (RWF) between post-training and the baseline conditions with "*" p < 0.001, or "†" p < 0.0001.
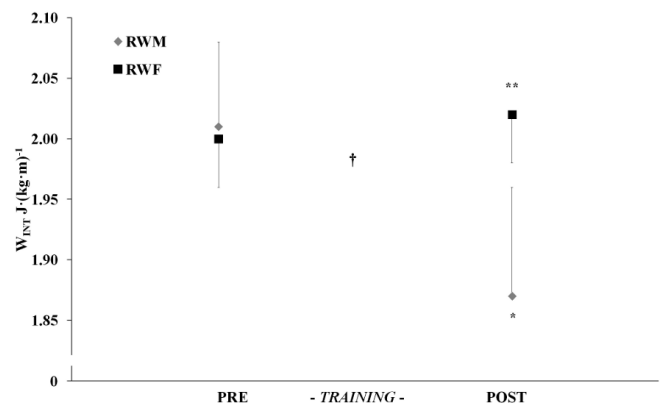
FIG. I. Changes in the WINT variable (means and SE) for the stride frequency manipulation (RWM) and free stride frequency groups (RWF) depending on the time (pre- and post-training). "†" represents significant (p < 0.0001) training × time interaction; "*" p < 0.05 and "**" p < 0.01 represent significant differences between pre- and post-training.

With regard to the two training strategies, within the RWM group the CT significantly increased by 4.58% (p < 0.001), as did SL (4.54% with p < 0.0001) between pre- and post-training (Table 1). SF and W_{INT} (Figure 1) also significantly decreased by 4.44% and 7.09% (p < 0.0001 with p = 0.03), respectively, within the RWM. Conversely, in RWF the SL and CT decreased by 1.18% with p < 0.0001 and <1% with p < 0.0001, respectively, between pre- and post-training, while the SF and W_{INT} increased (1.19% with p < 0.0001) respectively.

DISCUSSION

The current study shows for the first time the effect of stride frequency manipulation on kinematic parameters during uphill training in national race walkers. The study investigated the effects of two types of uphill RW training – RWM and RWF. The uphill training aimed to reproduce the same stride length that was elicited during RW on a level gradient. Uphill RW speed was therefore slower compared to level RW, 12.11 ± 0.56 km·h^{-1} and 12.83 ± 0.59 km·h^{-1}, respectively. The previous research that carried out RW training programmes used greater slopes, which produced higher speeds [6]. Such conditions would produce unnatural conditions for race walkers [31,32]. This would presumably increase the energy cost of RW [15,33] and lead to improvements in the cardiovascular system. Within the current study, the aim was to look at kinematic parameters and maintain a similar metabolic cost; due to this, IES was used [13].

In the present study the reduction in speed [13] allowed for effective stride frequency manipulation. Research suggests that race walkers often unconsciously select a stride frequency which minimizes injury and energy expenditure [8,23] and is modulated by the central pattern generators [34], as in running [24]. Due to this notion, race walkers within the RWM group found it problematic during the first training session to alter their stride pattern. The RWF group, however, did not have such issues, as stride frequency was freely chosen. The results following six uphill training sessions (over 3 weeks) suggest that the RWM group elicited kinematic improvements. Conversely, the RWF group did not show any significant kinematic improvements. Some researchers suggest that successful running race performances are characterized by increased stride length, increased cadence becomes more important at greater speeds [35,36] and contact times are shorter. Our results support this approach, and following training the RWM group increased SL by 4.54% with p < 0.0001 related to decreased W_{INT} (7.05% p < 0.05; Figure 1). During training the RWM group subjects were required to reduce their mechanical pattern in order to reduce their stride frequency (~5%).

Changes in CT were also evident: RWM increased by 4.58% (p < 0.001), but only a <1% decrease was found for the RWF group. The decreases in CT may have produced greater peak vertical force [37], thus providing longer stride lengths. This was supported within the RWM group in the current study. The kinematic adaptations elicited by the RWM group were characteristic of better race walkers, as energy efficient performances are. Longer contact times and smaller stride frequencies are associated with energy efficiency [13,38]. A particular limitation of this study, concerning the low sample size, can be explained considering the kind of discipline involved: in the last 30 years the mean number of subjects studied in the laboratory was very low (male, $n=7\pm4.5$; female $n=4\pm2.7$ [1]), due to the specificity of the RW technique.

CONCLUSIONS

In conclusion, this study showed how the stride frequency manipulation during uphill RW training alters subsequent level RW kinematics, and presumably aids efficient RW performance. The increase in SL could provide an advantageous alteration to kinematics. Because of the direct positive relationship between SL and speed, increasing SL could significantly increase the speed (which is the race walker's aim), assuming that the foot does not advance too far ahead of the centre of mass, providing a braking effect [39]. Considering that the RW race (50 km) record is 3 h 32 min 33 s [40], and the stride length decrease is 4% [3], this study could be useful in closing this gap with the training method of increasing athletes' stride length, leading to the first time an athlete could complete a race under 3 h 30 min The same training protocol could also be applied for a middle distance race (20 km), where a decrease of stride length by 2.4 and 2.7% was observed in males and females respectively between the last and first kilometres [12]. An uphill race walking protocol (changing stride frequency) could be useful to diversify athletes' common training protocol without stressing their current metabolic demand. In addition, given that several physiological systems are involved during RW, the possible effect of combining different training strategies, shown to be effective in isolation, warrants future studies.

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