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IS THE RACEWALKING BIOMECHANICS SIGNIFICANTLY INFLUENCED BY COACHING?

ALI VADBA POMEMBNO VPLIVA NA BIOMEHANIKO TEKMOVALNE HOJE?

ABSTRACT

While there is a significant number of analyses of influence of coaching and training content on performance, detailed analyses linking teaching the technique and biomechanics indicators in literature are rather scarce. The purpose of the study was to determine the differences between two groups of racewalkers in the selected variables describing their gaits. The research method consisted of measuring ground reaction forces as well as kinematics of motion recorded by video cameras and the OptoJumpNext system of 14 athletes from two distinct training groups of athletes walking at individually determined speed. To identify the differences in 9 key variables between the two groups, a two-sample unpaired T-test was performed, which was also controlled by Cohens' effect size indicator. The main finding of the study is that 5 key variables unrelated to walking speed were statistically different between the two groups, with Group A (predominantly "M"-shaped) having a lower ratio of peak ground reaction force (GRF) to GRF at 70% of the contact phase (p=0.0000), lower ratio of total GRF at the end and beginning of the interval 70% - 80% (p=0.0006), greater pelvic rotation (p=0.0056) and a more upright posture with lower forward pelvic tilt (p=0.0001) and lower backward thoracic tilt (p=0.0000). There were no significant differences between the two groups in two variables describing upper body movement i.e. arm-swing angle and thoracic rotation. Another variable (peak GRF) was also statistically different between the two group (p=0.0000), but this variable is related to the walking speed, which was not identical for the two groups. In conclusion, differences in the selected biomechanical indicators, that are trainable according to literature, may have been influenced by apparently different training approaches applied within the two groups of athletes. We suggest that, although the gait in racewalking is rather strictly defined by the rules, the above variables can and should be controlled and influenced by training to develop a smooth racewalking technique with lower peak ground reaction forces.

Keywords: racewalking gait, training groups, ground reaction forces, kinematics

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IZVLEČEK

Medtem ko obstaja veliko število analiz vpliva vsebine treniranja in vadbe na uspešnost, pa je podrobnih analiz, ki bi povezovale poučevanje tehnike in biomehanskih kazalnikov v literaturi precej malo. Namen raziskave je bil ugotoviti razlike med dvema skupinama tekmovalcev v tekmovalni hoji pri izbranih spremenljivkah, ki opisujejo njihovo hojo. Raziskovalna metoda je obsegala merjenje sil reakcije tal ter kinematike gibanja, posnetih z video kamerami in sistemom OptoJumpNext 14 športnikov iz dveh različnih vadbenih skupin atletov, ki so hodili z individualno določeno hitrostjo. Za ugotavljanje razlik v 9 ključnih spremenljivkah med obema skupinama je bil izveden dvosmerni neparni T-test, ki je bil kontroliran tudi z velikostjo učinka (Cohenov koeficient). Glavna ugotovitev študije je, da se je 5 ključnih spremenljivk, ki niso povezane s hitrostjo hoje, statistično razlikovalo med obema skupinama, pri čemer je imela skupina A (pretežno v obliki črke "M") manjše razmerje med največjo silo reakcije tal (GRF) in GRF pri 70 % kontaktne faze (p=0.0000), nižje razmerje med skupno GRF na koncu in začetku intervala 70-80 % (p=0.0006), večjo rotacijo medenice (p=0.0056) in bolj pokončno držo z manjšim nagibom medenice naprej (p=0.0001) in manjšim nagibom prsnega koša nazaj (p=0.0000). Pri dveh spremenljivkah, ki opisujeta gibanje zgornjega dela telesa, tj. kotu zamaha roke in rotaciji prsnega koša med skupinama ni bilo pomembnih razlik. Tudi druga spremenljivka (največja GRF) se je statistično razlikovala med obema skupinama (p=0.0000), vendar je ta spremenljivka povezana s hitrostjo hoje, ki pri obeh skupinah ni bila enaka. Skratka, na razlike v izbranih biomehanskih kazalnikih, ki jih je glede na literaturo mogoče vaditi, so lahko vplivali očitno različni pristopi k vadbi, uporabljeni v obeh skupinah športnikov. Predlagamo, da kljub temu, da je hoja pri tekmovalni hoji dokaj strogo določena s pravili, je mogoče in treba zgornje spremenljivke nadzorovati in nanje vplivati z vadbo, da bi razvili gladko tehniko tekmovalne hoje z manjšimi največjimi silami reakcije tal.

Ključne besede: tekmovalna hoja, vadbene skupine, sile reakcije tal, kinematika

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INTRODUCTION

Race walking is an integral part of the international long-distance competition program at World Track and Field Championships and Olympic Games. Although the name is reminiscent of walking as a pedestrian, the speed of movement in racewalking is much closer to running. However, the biomechanics of racewalking differ significantly from walking and running due to the specific rules (World Athletics, 2022) that require foot contact with the ground visible to the human eye throughout the gait as well as knee extension in the first phase of the stride.

The rules of racewalking define the technical requirements of the racewalking gait rather narrowly, which therefore seems very stereotypical (Preatoni et al., 2010). This gait is also not gender-specific, and there are no significant differences between kinetic and kinematic variables between female and male (elite) athletes when speed is taken into account (Hanley and Bissas, 2016). Nevertheless, studies have shown that individual differences in technique and style can be quite large, especially between less experienced athletes (De Angelis and Menchinelli, 1992), (Neumann et al., 2006), (Hanley et al., 2014). The most obvious difference studied is the shape of the vertical ground reaction force (GRF) curve, i.e., the 'M' and 'N' shapes, which can be associated with different racewalking styles (Fenton, 1984), (Pavei et al., 2019). However, due to the fact that there are much less racewalkers than runners, there is not much research on the biomechanics of racewalking and also there is a problem with sample size.

Pavei et al. (2014) conducted review of literature on the racewalking biomechanics and cited 16 papers focused on racewalking kinematics, 5 paper dealing with joint power and efficiency, only 4 papers analysing ground reaction forces and no more than 3 papers with combined analytical methods. Only 3 studies included more than 20 participants (while conducted using solely cameras), 6 studies had number of participants in the range 11-20 and 19 papers reported analyses with up to 10 participants (Pavei et al., 2014). Some conclusions can be drawn from a large number of studies on the biomechanics of long-distance running (Bowser et al, 2018; Chan et al., 2018; Doyle et al., 2022). Although running technique and style appear to be relatively uniform, significant differences in individual biomechanical variables between runners have become apparent with advances in analytical tools. Several studies have found differences in running style between recreational athletes and elite athletes who run as part of their (other) sport. In a systematic review of the impact of the foot strike technique on running injuries, Burke at al. (2021) isolated 13 studies with altogether 2564 participants, whereby 11 studies included recreational, collegiate, and military participants. Apart from that, Hanley et al. (2022) identified two characteristic groups of runners among the English Premier League soccer players, namely air runners ("gazelles") with shorter contact times, longer flight times, higher peak vertical forces, and greater vertical displacement compared to ground runners ("grizzlies").

A number of intervention studies have been conducted on the effects of different training methods compared to a control group, showing that differences in biomechanical variables, i.e., running style, can lead to differences in running economy and ground reaction forces, both of which are important for long-term athletic performance (Trowell et al., 2020). It is believed that coaches use somewhat different training methods when teaching running and racewalking technique and style, and also use specific strength and conditioning methods that may lead to individual biomechanical differences between athletes, which can also be considered an intervention (Saunderset al., 2004). However, there is very little comparative research on the biomechanics of different "real-world" training groups in running and racewalking, and there is no clear evidence that belonging to different training groups leads to significant differences in biomechanics, while researchers have predominantly concluded that elite athletes appear to have adopted their running style through a process of self-optimization (van Oeveren et al., 2021).

There is reason to believe that the effects of coaching are more pronounced in racewalking than in running for two main reasons. First, most track and field clubs have only one coach who specialises in racewalking because the number of athletes in racewalking is much smaller than in running, so the training methods are more unique than for runners, who typically change coaches several times at a young age until they join a group of elite runners. Unlike in running, coaches in racewalking usually spend many years teaching athletes the particular technique of locomotion and training their strength and conditioning to develop specific skills to achieve a competitive pace while following the rules that define an "unnatural" or restricted form of locomotion while keeping the risk of injury low (Hanley et al. 2014).

The purpose of this study is to determine if there are significant differences in the selected biomechanical variables between the two different groups of racewalkers that can be attributed to coaching, i.e., the different approach to teaching the racewalking gait. The research included 3 kinetic variables (peak GRF in the first phase of the stride, ratio of the peak GRF in the first phase of the stride and GRF at 70% of the single support phase, ratio of GRF at the end and beginning of the interval 70% -80% of the single support phase) and 7 kinematic variables (duration of the flight phase, ratio of the phases of the rear support and front swing, arm swing, thoracic rotation, pelvic rotation, thoracic tilt and pelvic tilt). Potential significance of this study is to contribute to the scarce research into impacts of coaching on technical performance within athletics, with practical implications to suggest which key indicators of racewalking biomechanics should be monitored and influenced in supporting the development of young athletes.

METHODS

Participants

The presented analysis is one of the results of larger research into racewalking biomechanics including 26 participants from 4 countries. While analysing a number of selected indicators that may be important for identifying smooth and efficient racewalking technique, we noticed rather large differences in some important indicators describing motion of the athletes from different countries i.e., training groups led by different coaches. Therefore, we isolated 14 athletes from two distinct training groups (A and B) with the same gender structure (3 females and 4 males) and similar average age of the athletes (19.3 ± 4.5 years for Group A and 20.3 ± 6.5 years for Group B). Athletes in Group A were slightly taller (173 ± 3.5 cm) than those in Group B (169 ± 9.3 cm), while body mass index was similar (20.8 ± 2.0 kgm^{-2} and 20.3 ± 1.9 kgm^{-2}, respectively) (Table 1).

Table 1. Basic data on participating athletes (averages with standard deviations, tests of distribution normality and differences between the two groups of athletes).

	Group A			Group B			T-test p-values	Mann-Whitney U-Test Prob>|z|
	Mean (st.dev.)	Kurtosis	Skewness	Mean (st.dev.)	Kurtosis	Skewness		
Age (years)	19.3 *(±4.5)*	5.30	2.24	20.3 *(±6.5)*	6.75	2.58	0.7436	0.6436
Body mass (kg)	62.4 *(±7.0)*	2.25	-1.36	58.1 *(±9.8)*	-1.86	0.15	0.3725	0.3379
Height (cm)	173 *(±3.5)*	1.08	0.75	169 *(±9.3)*	-1.72	0.40	0.2840	0.3379
Body mass index (kgm^{-2})	20.8 *(±2.0)*	1.31	-0.78	20.3 *(±1.9)*	3.68	1.78	0.6228	0.2774
Speed in competition (ms^{-1})	3.14 *(±0.2)*	1.69	1.33	3.41 *(±0.3)*	1.84	-1.22	0.0728	0.0476
Competitive results (a)	787 *(±176)*	0.92	0.12	876 *(±139)*	2.79	-1.66	0.3114	0.1797

(a): Best result achieved in racewalking in the last 12 months prior to testing, in terms of comparable scores, according to the Scoring Tables of Athletics, 2022 Revised edition, 2022 World Athletics

All presented variables are identified as having normal distribution for both groups while, as suggested by Kline (2023), data severely deviate from normality if the values of skewness and kurtosis are above 3 and 10, respectively. Using parametric T-test as well as non-parametric Mann-Whitney U-Test (due to the small sample size), no statistically significant differences between the two groups were identified, apart from competitive speed, according to the performed non-parametric test. Although most athletes from both groups were internationally competitive, the structure of the sample from the two countries was not identical in terms of the level of athletic results, and athletes from Group B had 8.6% higher competitive speed, while it was not possible to have participants with identical levels of performance because the total number of active athletes in racewalking is very small.

Protocol of data collection

Athletes were instructed to restrain from heavy training sessions 3 days before the test. Before the test, anthropometric variables were measured according to the International Biological Program (IBP). Body weight, height, and leg length were used in this study.

The test field was 3 x 1.5 metres, with a force platform (Kistler, Winterthur model 9286 600x400 mm) in the centre and an OptoJumpNext system (Microgate, Bolzano, Italy) on the sides of the field (5 m). To capture the motion images in all 3 planes, cameras (Panasonic DMC-FZ200, Osaka, Japan) were placed in front of the test field, on the right side perpendicular to the athletes' direction of motion, and above the test field. The motion images were filmed at 200 frames/s. After a 15-minute warm-up period, athletes repeatedly racewalked through the 45-metre track and test field until they completed 12 correct trials (6 for each leg) within the specified speed range and with correct positioning of the leg in the centre of the force platform, without any noticeable change in the walking style. Walking speed was set within +/- 5% of the individually determined speed achieved in the year prior to testing in the racewalking disciplines in which the athletes specialised to capture the biomechanics of their individual competitive speed. The speed was determined for senior athletes based on their results in the 50-km disciplines, for the U20 and male U18 athletes in the 10-km disciplines, and for the others in the 5-km racewalking disciplines. While the percentage of failed attempts was 55% (38% due to excessive speed and 17% due to incorrect positioning of one leg), a total of 370 attempts were made to achieve the required 168 correct shots.

Ground reaction force data were extracted as comma-separated values (CSV) files and aggregated to 1/10 s level for further data analysis. To avoid the effects of background noise, a threshold of 20 N in the vertical GRF was defined as foot strike and toe-off. Data recorded by the cameras were processed in Kinovea software and combined with data exported from the force plate and OptoJumpNext software to create a comprehensive database in which each individual trial represents a single row of all data for that trial. Force plate data were collected using LabChart software and the PowerLab A/D converter (AD Instruments, Dunedin, New Zealand). The sampling frequency was 2000 Hz. Data were filtered to select 3 of 6 recordings that were closest to the average GRF curves using the least squares method. Final variables were calculated as simple averages of the data for these 3 trials and normalized to body weight.

Statistical analysis

The analysis focused on the selected 3 kinetic variables and 7 kinematic variables (Table 2). The peak value of the total (resulting) GRF in the first phase of the step (as a percentage of body weight) was used. The ratio between the peak GRF in the first phase of the step and GRF at 70% of the contact phase was defined as the numerical interpretation of the shape (M or N) of the GRF curve. The third kinetic variable was defined as the ratio of GRF at the end and at the beginning of the interval from 70%-80% of the contact phase, while the slope of the GRF curve can be an important indicator of how the athletes were able to maintain the force to the ground immediately before toe-off. The kinematic variables, i.e., duration of flight phase, the rear support and front swing phases ratio, arm swing, thoracic and pelvic rotation, and thoracic and pelvic tilt, were selected as variables considered as important and specific for race walking.

Table 2. Variables and measuring methods.

Variables	Units	Description	Measuring methods
Kinetic variables			
Peak GRF in the first phase of the stride	Percentage of body weight	Total resultant GRF (% of body weight); indicator of risk of contracting injuries	Measured by Kistler force plate
Ratio of the peak GRF in the first phase of the stride and GRF at 70% of the single support phase	Ratio	Total resultant GRF; indicator of the shape (M or N) of the GRF curve	
Ratio of GRF at the end and beginning of the interval 70% -80% of the single support phase (GRF curve slope)	Ratio	Total resultant GRF, indicator of the slope of the GRF curve immediately before the toe off	
Kinematic variables			
Duration of the flight phase	Milliseconds	Time lapse when no foot contact with the surface	Measured by OptoJumpNext
Ratio of the phases of the rear support and front swing	Ratio	Ratio of distance between back leg toe and the vertical line connecting center of the mass and ground and distance	Captured by the camera placed on the side of the testing field and processed using the Kinovea software

		between that line and front leg heel in the double support phase	
Arm swing	Degrees of angles	Maximal angle between upper arms projection in the sagittal plane	Captured by the camera placed on the side of the testing field and processed using the Kinovea software
Thoracic rotation	Degrees of angles	Angle between the line through acromions and coronal plane.	Captured by the camera placed above the testing field and processed using the Kinovea software
Pelvic rotation	Degrees of angles	Angle between the line through iliospinale and coronal plane.	Captured by the camera placed above the testing field and processed using the Kinovea software
Thoracic tilt	Degrees of angles	Angle between the line through acromion and illiospinale and coronal plane in the midstance	Captured by the camera placed on the side of the testing field and processed using the Kinovea software
Pelvic tilt	Degrees of angles	Angle between the line through trochanterion and illiospinale and coronal plane in the midstance	Captured by the camera placed on the side of the testing field and processed using the Kinovea software

All presented variables (Table 3) are identified as having normal distribution regarding skewness and kurtosis. One variable (duration of flight phase) had the F-test ratio of variances between two groups above the critical value and for this variable, T-test was not performed. For other 9 variables, the unpaired two-sample T-test was performed to investigate whether there were significant differences in the key variables between the two groups of athletes, also using Cohens' effect size test. Apart from that, having regard to the small sample size, the parametric analysis was complemented with non-parametric Mann-Whitney U-Test. Considering the differences in speed between the two groups, the coefficient of determination was calculated for all variables in a linear regression with over ground speed. The significance level (probability of rejecting the null hypothesis if true) for all analyses was set at $p < 0.05$ and for Cohens' effect size critical value was set at $d \geq 0.8$. Data analyses were performed using Microsoft Excel Data Analysis tools and Stata 18.0 software package.

Table 3. Descriptive analysis of the variables.

Variables	Group A			Group B			F-test for ratio of sample variances (critical value = 2.58
	Mean (st.dev)	Kurtosis	Skewness	Mean (st.dev)	Kurtosis	Skewness	
Kinetic variables							
Peak GRF in the first phase of the stride (% BW)	1.80 *(±0.16)*	0.00	0.98	2.40 *(±0.23)*	0.49	0.07	2.11
Ratio of peak GRF in the first phase of the stride (% BW) and GRF at 70% of single contact phase	1.32 *(±0.17)*	-0.02	0.72	1.89 *(±0.25)*	0.58	0.98	2.06
Ratio of total GRF at the end and beginning of the interval 70% - 80% of single contact phase	0.74 *(±0.06)*	1.96	-0.18	0.64 *(±0.08)*	-1.59	-0.01	2.01
Kinematic variables							
Duration of the flight phase (ms)	36.3 *(±10.2)*	-0.09	-0.42	50.8 *(±18.0)*	-0.51	-0.42	<u>3.10*</u>
Ratio of phases of rear support and front swing	2.07 *(±0.34)*	0.85	0.79	2.36 *(±0.39)*	-1.05	0.17	1.34
Arm-swing angle (degrees)	80.7 *(±15.7)*	-1.22	-0.41	78.5 *(±13.8)*	-1.31	0.07	1.30
Thoracic rotation (degrees)	17.3 *(±6.0)*	0.18	-0.81	17.3 *(±7.5)*	-1.55	0.22	1.53
Pelvic rotation (degrees)	15.4 *(±5.4)*	0.39	-0.80	9.9 *(±4.1)*	-0.57	0.50	1.76
Thoracic tilt (degrees)	-7.6 *(±3.9)*	-0.56	-0.70	-18.8 *(±3.9)*	-0.39	0.31	1.01
Pelvic tilt (degrees)	5.6 *(±4.1)*	-0.70	0.73	13.0 *(±4.4)*	-0.75	-0.43	1.16

Legend: * denotes F-test value which is above the critical value.

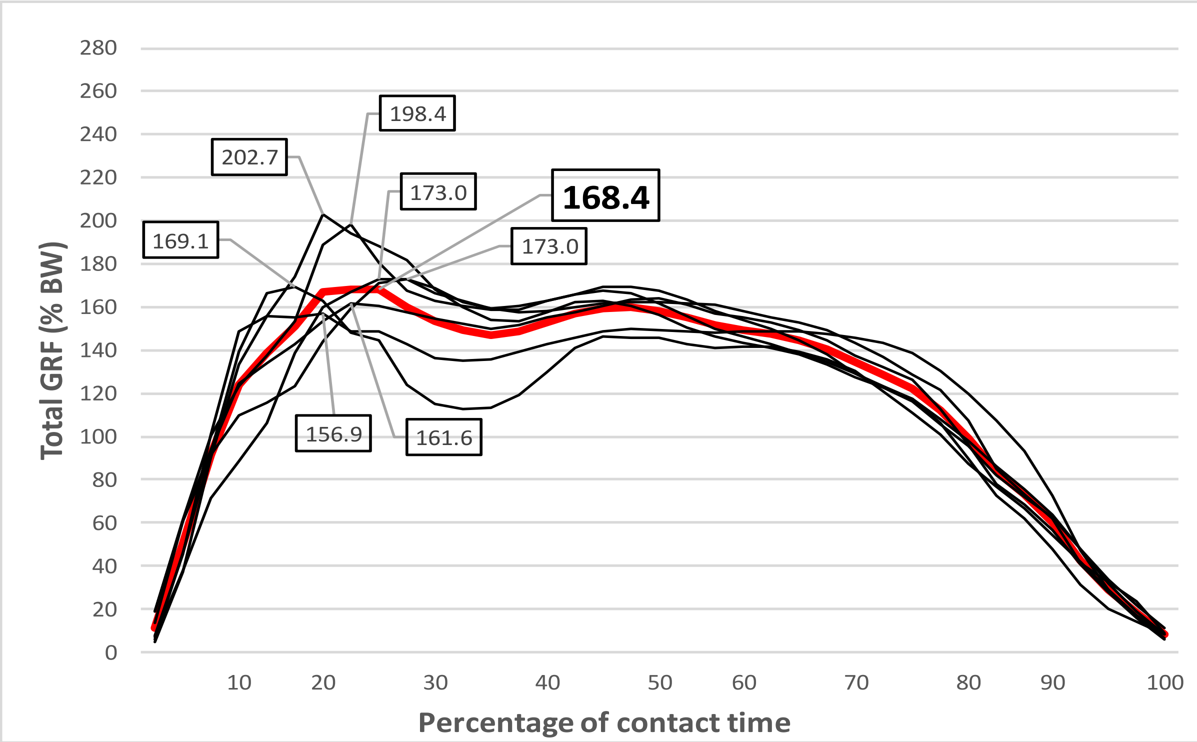
Ethics

The Scientific and Ethical Committee of the Faculty of Kinesiology in Zagreb, Croatia, approved the study protocol before recruitment of participants (Approval No. 60/July 2019), and the research was conducted in accordance with international ethical standards and adhered to the current Declaration of Helsinki of the World Medical Association. Adult athletes and parents of minor athletes signed an informed consent form to participate in the study.

RESULTS

The differences in the shape of the total GRF curves (relative to body weight) between the two groups of racewalkers were striking. In Group A, 6 out of 7 athletes had the "M"-shaped type of GRF curves, while in Group B, 6 out of 7 athletes had predominantly "N"-shaped GRF curves. To illustrate this, we calculated the average GRF curves for both groups of the athletes. Group A athletes (Figure 1) have a very low peak total GRF (168.4% of body weight) and they maintain the force towards ground throughout the midstance, where the second maximum occurs, not much lower than the first one. Towards the toe-off, the Group A athletes show the steep curve only in the last 25% of the contact time.

Figure 1. Total GRF (% of body weight) for Group A athletes.



The peak total GRF for the athletes in Group B (Figure 2) was "N"-shaped" with very large maximum (227.5% BW). These athletes are not able to retain the force throughout the stride and the midstance GRF is much lower than maximum, while there was a steep decline after the maximum, a period of maintenance of the GRF towards the midstance and very high curve slope beginning approximately from the midstance.

Figure 2. Total GRF (% of body weight) for Group B athletes.

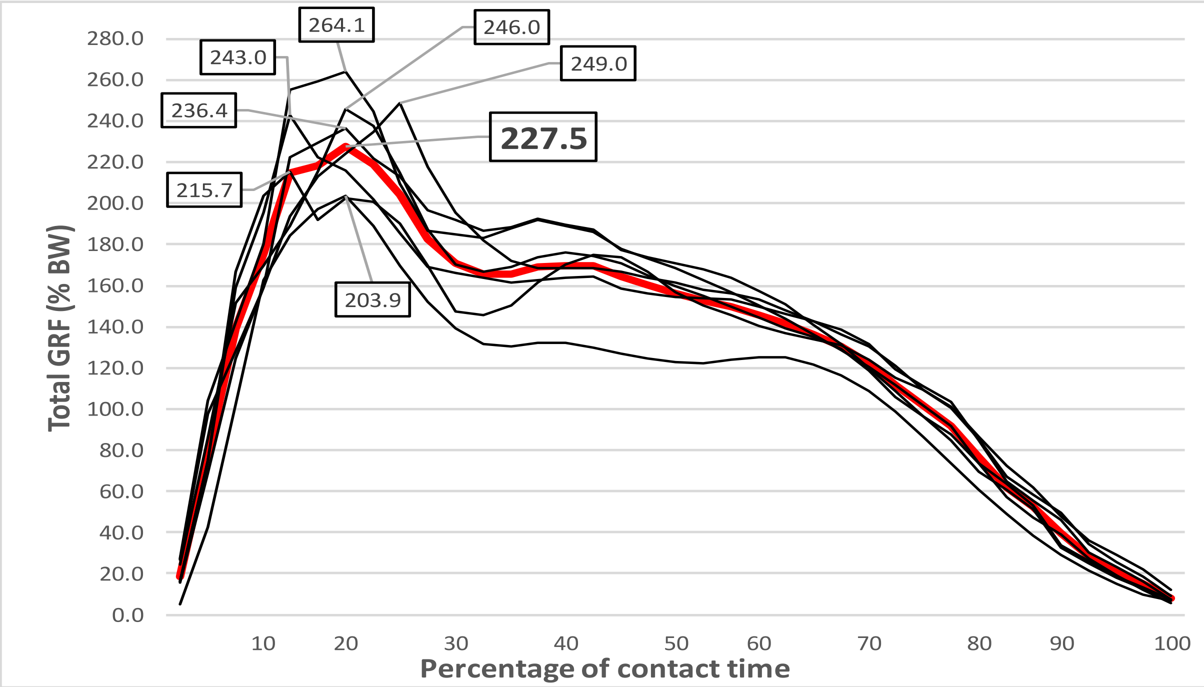


Table 4 summarises the main findings of the analysis of the differences between the 2 groups of racewalkers in the 9 selected variables. By simply calculating the relative differences, that is the average values for Group B expressed as index values (Group A = 100) it is evident that only for 2 variables (arm swing and thoracic rotation) the differences were less than 10%. For 2 other variables (ratio between the rear support and front swing and the curve slope), the differences were moderate (10%-30%). For other 3 variables (peak GRF in the first phase of the stride, the curve shape and pelvic rotation) the differences were high (30%-50%). For 2 variables the differences were extreme with the Group B athletes having forward pelvic tilt 2.3 times larger and backward thoracic tilt 3.2 times larger than the Group A athletes.

Table 4. Main findings of the research.

Variables	Group B mean (Group A mean = 100)	T Test (p-values)	Cohens' Effect Size	R^2 in regression with speed	Mann-Whitney U -test Prob>lzl
Kinetic variables					
Peak GRF in the first phase of the stride (% BW)	133.7	0.0000	3.11	0.34*	0.0000
Ratio of peak GRF in the first phase of the stride (% BW) and GRF at 70% of single contact phase (curve shape)	143.2	0.0000	2.65	0.14	*0.0000*
Ratio of total GRF at the end and beginning of the interval 70% - 80% of single contact phase (curve slope)	85.8	0.0006	-1.48	0.06	0.0018
Kinematic variables					
Ratio of the phases of the rear support and front swing	113.7	0.0489	0.78*	0.13	0.0506*
Arm-swing angle	97.3	0.6949*	-0.15*	0.02	0.6623*
Thoracic rotation	100.0	1.0000*	0.00*	0.02	1.0000*
Pelvic rotation	64.7	0.0056	-1.14	0.09	0.0087
Thoracic tilt	316.9	0.0000	-2.44	0.15	0.0000
Pelvic tilt	233.3	0.0001	1.76	0.09	0.0004

Legend: "R^2 in regression with speed" are values of coefficients of determination, describing the proportion of the variation in the analyzed variables predictable from speed over ground of participants. Denoted with "*" are values that have R^2 values larger than 0.25, T-test p-values larger than 0.05, those with Cohens' Effect Size lower than 0.8 as well as those with Mann-Whitney U-Test values larger than 0.05.

According to the performed T-test, there were no significant differences between the two groups for two variables describing upper body movement (arm swing angle and thoracic rotation). For the variable on the ratio of the phases of the rear support and front swing, T-test p-value was slightly within the set critical value (0.05), while the Cohens' effect size test resulted with the value very close but still below critical (0.8) so difference between the 2 groups cannot be considered as statistically important. These 3 variables were also outside the critical values to indicate statistical differences between the two groups of athletes according to the non-parametric Mann-Whitney U-Test.

Further 5 variables (2 kinetic and 3 kinematic variables) have clear statistically significant differences between the two groups of athletes. Not surprisingly, the variables representing the shape and slope of the GRF curve are significantly different between the two groups, with Group A (predominantly "M"-shaped group) having a much lower ratio of peak GRF to GRF at 70% of the contact phase and less steep GRF curve in the 70% - 80% interval, which is also evident from the presented figures. Regarding the kinematic variables, the larger pelvic rotation angle, smaller forward pelvic tilt, as well as much smaller posterior thoracic tilt of the Group A athletes are significantly statistically different than for the Group B athletes.

Withstanding the fact that there was a difference of 8.6% in the average speed of movement between the two groups, which could affect the conclusions, it is important to note that all 5 variables that are statistically significantly different between the two groups, as well as 3 variables that are not, are not statistically influenced by the speed, with R^2 in regression with speed lower than 0.15. The remaining variable (peak GRF in the first phase of the stride) is moderately related to the speed of movement (R^2=0.34) and, although this variable is statistically significantly different between the two groups, this shall be interpreted with caution.

DISCUSSION

The aim of the presented study was to investigate if certain biomechanical indicators are statistically different between two distinct groups of racewalkers. We concluded that out of 9 variables under review, 5 variables unrelated to walking speed (GRF curve overall shape and slope in 70% - 80% of the contact phase, pelvic rotation, thoracic and pelvic tilt) were statistically different between the two groups, as well as another variable (peak GRF) related to walking speed, which was not identical for the two groups.

Racewalking is a unique gait that is intermediate between running and walking, with greater pelvic rotation and peak moments of hip flexion and extension, and two distinct peaks of vertical ground reaction force, with the first peak being greater (Norberg, 2015). Although a visible flight phase is not allowed by the regulations, electronic devices record the occurrence of a short flight phase at competition speed in all international athletes. In elite racewalkers, flight time is positively correlated with racewalking speed (r = 0.46) and loading peak forces (r = 0.47) (Hanley and Bissas, 2016). In our study, flight time was also moderately correlated with speed (R^2 = 0.38) and was on average much longer (40%) in the "N"-shaped group than in the "M"-shaped group, while the difference in speed was only 8.6%. Similarly, the difference in peak GRF was 33.7% higher in the "N"-shaped group than in the "M"-shaped group. This increase of GRF for 1 unit of velocity increase was above the 2.22 average in our study, and much above the 0.23 value in a similar study (Pavei and La Torre, 2016). However, in the cited study, increase of speed was analysed for individual elite athletes, each of whom walked in a different speed range, whereas our study included less experienced athletes that walked in a single, individually determined narrow speed range matched to their competitive speed. These considerations, together with the analysis presented, lead to the conclusion that the variable of peak relative GRF may also be group-specific, while exhibiting satisfactory T-test statistics.

Fenton (1984) found that 4 of 7 well-trained racewalkers exhibited the "N-shaped" GRF curve with a characteristic peak at GRF in the first 25% of the support phase and a sharp drop in the last 25% of the support phase. For 3 less trained subjects, he described the "M-shaped" curve with an earlier occurrence of the peak GRF, a sharp drop to a low level thereafter, and a distinct second peak at about 75% of the support phase. Since the first group was better trained than the second, he concluded that their walking style was more advanced and "fluid". In a more recent study (Pavei and La Torre, 2016), 7 of 15 racewalkers had an "M-shaped" (vertical) GRF curve and 8 athletes had an "N-shaped" curve, and the outcome level of the two groups of athletes could not be clearly distinguished, which is contrary to the results of Fenton (1984). The cited authors hypothesised that the shape of the GRF curves was a result of the learned style of racewalking being specific to the training group, while differences in style and specific abilities could be the cause. However, they did not have enough subjects from the same clubs, so they could not prove this assumption. Our study could be a formal proof of this assumption, because out of 14 racewalkers from 2 training groups, 6 in one group had an N-shaped curve and 6 in the other group had an M-shaped curve. The variable representing the shape of the GRF curve numerically (ratio of peak GRF to GRF at 70% of the contact phase) and the variable focusing on the slope of the curve in the interval of 70%-80% of the contact phase were clearly statistically different between the 2 groups.

It should be emphasised that previous studies focused mainly on the vertical component of the GRF, while our work focused on the entire GRF, following the principal component analysis approach, which takes into account the entire time series of the three-dimensional GRF data (Kim, Dai, Lu, Lu and Chou, 2022) and focused on the shear stress from the resultant GRF (Gruber, Edwards, Hamill, Derrick and Boyer, 2017), (Yu et al., 2021), which is also interpreted as the sum of all forces that determine the load during dynamic movements (Shimokochi and Shultz, 2008). The reason for this focus is that the risk of injury (an important issue in training) is not only related to the vertical component of the GRF but also to the other two components (Shelburne, Pandy, Anderson and Torry, 2004), (Napier, MacLean, Maurer, Taunton and Hunt, 2018). A smoother GRF curve (with less sharp peaks) is beneficial for walking efficiency due to less velocity fluctuations (Hanley and Bissas, 2013).

In our analysis, the group with the N-shaped GRF curve had a 35% lower pelvic rotation angle than the M-shaped group, whereas there were no significant differences between the two groups in thoracic rotation and arm swing angle (variables describing upper body movement). These results are consistent with recent research on the role of the upper body in racewalking (Gravestock, Tucker and Hanley, 2021), which found no correlation between upper body joint positions and pelvic motion with speed, but only a positive correlation between pelvic rotation and stride length. Apart from this, the N-shaped group in our study had more forward pelvic tilt (13.0 versus 5.6 degrees) and much more posteriorly tilted thorax (18.8 versus 7.6 degrees), whereas the M-shaped group had a more upright trunk posture. In racewalking pelvic tilt is thought to be reduced by the development of strong abdominal muscles (Gravestock, Tucker and Hanley, 2021), which is consistent with Drake's (2003) conclusion that a lack of trunk stability limits optimal flexion and extension of the hips, resulting in a bent knee or visible flight phase, which are clear technical errors in racewalking. The forward flexed upper body is also one of the few characteristics (along with rapid leg swing and short ground contact) that distinguish distance runners from East Africa from athletes from other regions (Tawa and Louw, 2018).

While comparative studies of biomechanical indicators of two or more training groups are very scarce in practice, there are a large number of so-called "intervention studies" that have shown that running style and running economy are 'trainable' parameters (Jones and Carter, 2000) and can be greatly improved in the short to medium term by a strength training program (Balsalobre-Fernández, Santos-Concejero and Grivas, 2006), plyometric training, resistance and interval training (Moore, 2016), and high-frequency running (Quinn, Dempsey, LaRoche, Mackenzie and Cook, 2021). There is also evidence that (verbal) coaching instructions can have an immediate effect on running style change, with a 17% reduction in peak GRF, which is an important risk factor for the occurrence of running injuries (Ó Catháin, Richter and Moran, 2022) as well as racewalking injuries (Qipeng, Zhengye, Dewei, Cui and Wei, 2013) with the most common injuries (43% of injuries in elite athletes at 12 months) occurring in the posterior tight muscles and tendons (Hanley, 2014). Also, intervention studies not including runners and racewalkers indicate that the most important differences identified in our research can be influenced by coaching i.e. applying specific tailor-made exercises. Wehner et al. (2021) conducted meta-analysis and four out of five studies demonstrated a significant improvement of thoracolumbar spine flexibility following the Tai Chi training. Also, Dimitrijević et a. (2022)

reported that different correction methods have a positive effect on subjects with lumbar lordosis (thoracolumbar flexion), according to 10 studies they included in meta-analysis.

Not only in running, but also in racewalking, kinematics can be influenced by training content (Witt and Gohlitz, 2008; Gravestock, Tucker and Hanley, 2021; Drake, 2003). Therefore, learned movement patterns specific to training in different training groups could be behind the differences in variables describing gait in racewalking discussed in this article, whereby racewalking is not a "natural" movement mode and is learned and trained with much greater effort than running or walking as a pedestrian. In conversation with the coaches of the two groups under review it became evident that the Group A (predominantly "M"-shaped) had a high share of multisport activities (running, cycling, kayaking) in total training volume (some 30%). They also had large content (up to 30%) of technical exercises, specific strength workouts, especially focused on stimulating thoracolumbar rotation and reducing thoracolumbar flexion while also reducing flight time and excessive GRF. Athletes within the Group B (predominantly “N” shaped) had much higher weekly racewalking mileage especially focused on competitive speed with multisport activities and technical exercises performed only occassionaly. As illustration of the measurable outcome of the difference in the contents of technical workouts between the groups, 3 athletes from the 2 groups each participated in European championships in the year prior to testing and Group A racewalkers did not receive any red card from the judges, while all 3 of the Group B racewalkers received at least 1 red card.

A potential problem with the N-shaped GRF curve is, as mentioned before, that higher peak at the heel contact leads to higher risk of strain-related injuries (Hanley et al. 2014), which leads us to practical implications of this study's findings, i.e., that coaches should consider instructing young racewalkers to maintain an upright body position, provide adequate pelvic rotation, maintain force toward the ground longer throughout the gait, and avoid excessive flight phase to maintain a lower peak GRF.

CONCLUSION

The results of our research strongly suggest that there are significant differences between two distinct groups of racewalkers, particularly in pelvic rotation, pelvic and thoracic tilt, as well as in the shape and slope of the GRF curve. According to the findings of research by other scholars, these indicators are connected to a smooth racewalking technique and can be influenced by instructional coaching. We therefore conclude that the reported differences in contents and focus of training between the analysed groups may have influenced the identified statistically significant and functionally important differences in the selected variables describing the racewalking gait. These characteristics can and should be controlled and modified in racewalking coaching to develop a motion technique within the set rules of racewalking, without excessive peak ground reaction forces, which is important for racewalking economy and injury prevention.

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