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GROUND REACTION FORCES OF NATIONAL LEVEL RACE WALKERS

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The purpose of this study was to measure and analyse ground reaction force variables during race walking. Fourteen national level race walkers, eight men and six women, walked at race pace over two force plates recording at 1000 Hz. Men and women had comparable force trace patterns except for the magnitude of the weight-loading peak force. There were similarities with normal ground reaction force patterns, although the drop in vertical force at midstance and subsequent rise in vertical push-off force typical of normal walking were not observed. This was considered to be due to the straightened knee rule of race walking and the need to reduce vertical displacment and flight time. The medial forces were greater than those in normal walking and this may be related to the frontal plane motions of the pelvis.

KEY WORDS: athletics, gait, kinetics, race walking, stance phase

INTRODUCTION: Typical ground reaction force (GRF) patterns in normal walking consist of a vertical component with two smooth peaks, the first corresponding to a weight-loading period after heel strike, and the second corresponding to a push-off phase ending with toe-off (Watkins, 2007). Both of these peaks normally have a magnitude above 1 bodyweight (BW); the short period during midstance between these peaks normally drops below 1 BW (Rodgers, 1993). The magnitudes of the weight-loading and push-off peaks is roughly equal (Whittle, 1996). In some cases, a short impact peak occurs within the first 0.05 s after heel strike and before the weight-loading peak (Watkins, 2007). The anterioposterior component also comprises of two main peaks roughly corresponding to the two main vertical peaks. The first occurs during weight loading and is associated with deceleration of the centre of mass; the second occurs during propulsion and causes acceleration of the centre of mass (Watkins, 2007). The medio-lateral component, which is usually smaller than the anterioposterior component, acts medially during the single support phase, and laterally during double support. The single support phase begins just after heel-strike and ends just before toe-off (Whittle, 1996), when the double support phase begins with the contralateral heel-strike.
Race walking is an abnormal form of gait where no visible loss of contact with the ground is permitted and the knee must be straightened from heel strike until the ‘vertical upright position’ (IAAF rule 230.1), which occurs when the centre of mass passes over the foot. The absence of knee flexion during early stance does not occur in normal walking (Inman et al., 1981) and may therefore have an effect on GRF patterns. The speed at which race walkers walk may also result in GRF patterns quite different from those observed in normal walking. As well as understanding the overall typical race walking GRF patterns, it will be useful to distinguish between the results found for men and women as their different body shapes may contribute to slightly different GRF patterns. The purpose of this study was to measure and compare GRF variables between national level male and female race walkers.

METHODS: Fourteen national level race walkers gave informed consent and the study was approved by the University’s ethics committee. The group of fourteen athletes was comprised of eight men (stature: 1.78 m (± .05); mass: 67 kg (± 9)) and six women (stature: 1.71 m (± .05); mass: 59 kg (± 5)). Each athlete race walked over two 900 mm X 600 mm force plates (Kistler, Winterthur) at a pace that was equivalent to their season’s best for 10 km (for the nine junior athletes) or 20 km (for the five senior athletes). There were no differences between junior and senior athletes for walking speed or any kinetic variable. Each participant wore their own competitive footwear and other clothing during testing. Timing gates were placed 4 m apart before and after the force plates to ensure the correct speed was attained (within 2% of the target speed). The athletes had a 25 m approach along an indoor running track to the force plates to achieve the correct walking speed and continued walking for a further 25 m after the force plates. The force plates were flush with the track and the sampling rate was 1000 Hz. Ground reaction forces were recorded from both left and right foot contacts within the same trial. Athletes completed at least ten trials each and the three closest to the target time were analysed provided there was no evidence of targetting by the walker. The three traces for both feet were also visually inspected to ensure consistency between trials. Averaged data for each athlete were calculated and independent *t*-tests conducted to compare values between men and women, with adjustments made if Levene's test for equality of variances was less than 0.05. An alpha level of 5% was set for the *t*-tests.

RESULTS: In Figure 1, typical patterns for the vertical, anterio-posterior and medio-lateral GRFs during a left foot stance phase in a female race walker are shown. A small anterior force with a magnitude of about 0.05 BW and lasting approximately 0.02 s which was recorded for the majority of athletes was not displayed by this particular athlete.

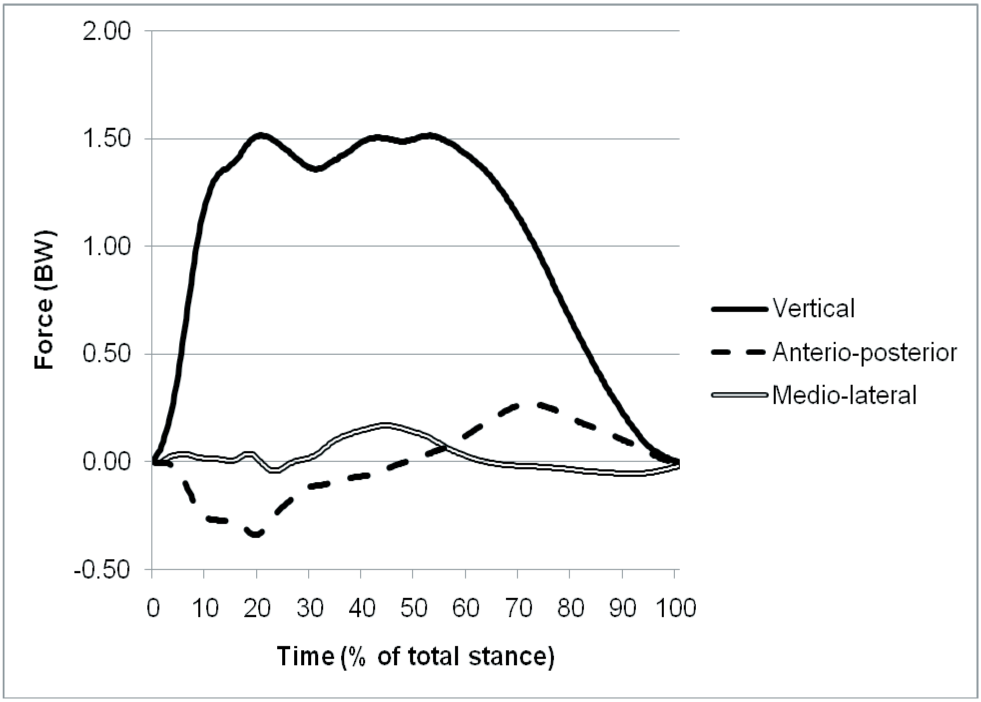

Figure 1: Ground reaction force traces for a national-level female race walker.

The magnitudes of several vertical force parameters of interest are shown in Table 1 below. Two men's and one woman's traces did not show distinct impact peaks, and no difference was found between men and women for this variable (t = .75, p = .473). Peak weight-loading force was however found to be higher in men than in women (t = 4.37, p = .001). However, there were no differences between men and women with regard to either midstance forces (t = 1.08, p = .301) or peak push-off forces (t = .16, p = .875). The mean time from heel strike to impact peak in men was 0.027 s (± .003) and in women 0.031 s (± .008), while the mean time from heel strike to the weight-loading peak in men was 0.062 s (± .008) and in women 0.063 s (± .009). This weight-loading peak time occurred at 22.3% (± 3.5) of stance time in men and at 21.6% (± 4.1) in women. The subsequent push-off peak force occurred at 57.8% (± 4.1) of stance time in men and at 58.3% (± 5.0) in women.

Table 1
Vertical ground reaction force data (mean ± SD)

	Impact peak (BW)	Weight-loading peak (BW)	Midstance force (BW)	Push-off peak force (BW)
Men	1.45 (± 0.42)	1.99 (± 0.26)*	1.61 (± 0.25)	1.54 (± 0.29)
Women	1.30 (± 0.21)	1.55 (± 0.17)	1.51 (± 0.08)	1.52 (± 0.14)

* Men's value significantly greater than women's ($p < .01$)

Anterio-posterior force parameters are shown in Table 2. There were no differences between men and women for either maximum braking force ($t = .15$, $p = .084$) or maximum propulsive force ($t = .15$, $p = .884$). The maximum braking forces for men occurred at 0.045 s (± 0.013) which corresponded to 16.0% of contact time. The maximum mean braking forces for women occurred at 0.049 s (± .014) which corresponded to 16.7% of contact. The braking to propulsion (%) data represent the instant of the stance phase at which the anterio-posterior force changed from a negative force to a postive one; there was no significant difference for this measurement ($t = 2.16$, $p = .051$). There was also no difference found for the instant of stance at which maximum anterior propulsion occurred ($t = .47$, $p = .648$). Small anterior forces (not shown in Figure 1 above) were recorded at heel-strike for both feet in nine athletes, for one foot in four athletes, and in neither foot in one athlete. The mean maximum of this force for men was 0.06 BW (± .03) and for women, 0.05 (± .03). In both men and women, its mean duration was approximately 0.02 s.

Table 2
Anterio-posterior ground reaction force data (mean ± SD)

	Maximum braking force (BW)	Maximum propulsive force (BW)	Braking to propulsion (%)	Time to max propulsion (%)
Men	0.43 (± .12)	0.28 (± .07)	40.0 (± 6.7)	74.0 (± 4.9)
Women	0.34 (± .09)	0.28 (± .07)	46.2 (± 4.1)	75.1 (± 3.7)

Medio-lateral force variables are shown in Table 3. There were no differences between men and women for maximum lateral force ($t = 1.34$, $p = .206$) or maximum medial force ($t = 1.57$, $p = .157$). Likewise, the instants during stance where the force changed from lateral to medial and returned from medial to lateral were not different between men and women ($t = .26$, $p = .799$ and $t = .87$, $p = .402$) respectively.

Table 3
Medio-lateral ground reaction force data (mean ± SD)

	Maximum lateral force (BW)	Maximum medial force (BW)	Lateral to medial (%)	Medial to lateral (%)
Men	0.13 (± .09)	0.15 (± .07)	26.1 (± 5.6)	61.7 (± 6.6)
Women	0.10 (± .05)	0.12 (± .05)	27.0 (± 8.1)	64.2 (± 5.8)

Step time was calculated for one step per trial (that recorded by the force plates). Step time and its components, contact time and flight time, are shown in Table 4. None of these three variables was found to differ between men and women (step time: $t = 1.35$, $p = .202$; contact time: $t = .97$, $p = .351$; flight time: $t = .20$, $p = .846$). Contact time is also shown as a percentage of step time. All athletes had a period of flight, ranging from 0.003 to 0.053 s.

Table 4
Step time, contact time and flight time data for each group (mean ± SD)

	Step time (s)	Contact time (s)	Flight time (s)	Contact time (%)
Men	0.308 (± 0.021)	0.282 (± 0.023)	0.027 (± 0.011)	91.4 (± 3.6)
Women	0.324 (± 0.023)	0.296 (± 0.032)	0.028 (± 0.014)	91.2 (± 5.0)

DISCUSSION: The purpose of this study was to measure and analyse GRF variables in national level race walkers. In the majority of race walkers, the vertical component of GRF had three distinct peaks similar to those in normal walking: an early impact peak followed by a weight loading peak, and a final push-off peak. The first two peaks occurred within the first 25% of stance. Although different from each other, the magnitude of the weight-loading peak for both men and women was greater than that found in normal walking. This was probably due to higher walking speeds. The vertical GRF component pattern did not then follow a typical normal walking pattern following the weight-loading phase. Rather than experiencing a drop at midstance with an increase to the push-off peak, the trace tended to follow a relatively flattened path. The lack of a drop at midstance may be due to the absence of knee flexion during the early part of stance. The decrease from weight-loading peak to push-off peak was 0.45 BW in men compared with 0.03 BW in women. The relatively low push-off peak may have been an attempt to prevent too great a vertical rise of the CM and a subsequent visible flight period. It is unlikely that the durations of flight measured in this study would be visible to the naked eye when judging. Nonetheless, such flight times should be minimised as much as possible in order to adhere to the rules of the event and reduce the risk of disqualification.
In the anterio-posterior direction, the periods of deceleration and acceleration typical of normal walking were also found. In addition, a short, small anterior force was recorded at heel-strike in most athletes which made a small contribution to the maintenance of forward momentum. This was probably due to a conscious attempt by the athletes to strongly extend the hip prior to and during contact. The peak deceleration force then occurred at an instant between the coincidental vertical peaks of impact and weight-loading. The acceleration peak, on the other hand, occurred approximately 17% of stance time after the vertical push-off peak and can be seen as a point where the race walker is attempting to maximise forward propulsion while restricting vertical displacement as described above.
In normal walking, a medial force occurs during single support and lateral forces during double support. However, because of the flight times recorded for these race walkers, the entire stance phase was in fact spent in single support. Nonetheless, the normal walking patterns was replicated to some extent as there was a lateral force observed in race walking at the beginning (for approximately the first 27% of contact) and end of stance (for approximately the final 37% of contact). The maximum medial force was greater than that of the maximum lateral force and this may have been in response to the lateral tilt of the pelvis towards the stance leg that typically occurs in race walking due to the straight knee rule.
The general pattern of motion for all three GRF components was very similar for both men and women and there were few differences for the variables measured in this study. In fact, weight-loading peak force was the only variable found to be significantly different. However, future studies should take care to compare between genders before combining any results.

CONCLUSION: The GRF pattern in race walking differed from normal walking because of the unique rules of race walking and because of increased speed. During the push-off phase, race walkers should aim to reduce vertical forces and to increase anterior forces in order to reduce unnecessary and possibly inefficient vertical lift of the centre of mass while generating forward momentum. Future research on the effects of the straightened rule on medio-lateral forces in particular is recommended.

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