ANGULAR KINEMATICS IN ELITE RACE WALKING PERFORMANCE

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The purpose of this study was to measure and analyse the important angular kinematic variables in elite race walking. Research has shown that these variables include knee angle at contact and midstance, rotation of the hips and shoulders, and hip extension velocity. Eighty elite race walkers were videoed during competition and analysed using 3D-DLT with SIMI Motion. The knee angle was found to be almost straight at contact in most athletes and hyperextended by the vertical upright position. Athletes varied in the amount of rotation at the hips and shoulders, with 50 km men having greater hip rotation and 20 km women having greater shoulder rotation. There was much more variation in the values found for elbow and shoulder angles. Very few angular measurements correlated with key race walking variables such as speed, step length and cadence.

KEY WORDS: race walking, angular kinematics, gait, athletics.

INTRODUCTION: Angular kinematics are of particular importance in race walking. First, the hip angle will determine how far the foot is in front or behind the body. Second, the knee is the most important joint to analyse during race walking as it is the only joint which has specific technical rules applied to it. The rules state that it must be straightened from the moment of first contact with the ground until the vertical upright position (IAAF rule 230.1), although the definition of 'straightness' is unclear. For example, Knicker and Loch (1990) defined angles in a range between 175 and 185° as representing a straight knee. Although an extended knee is abnormal when used in normal walking or running, a straight knee at landing may be of benefit to the race walker (Murray *et al*., 1983). Effective control of the pelvic girdle is important in increasing race walking speed (Hoga *et al*. 2000). This is partly because increased walking speed is achieved through decreasing support time by increasing hip extension velocity (Lafortune, Cochrane & Wright, 1989). Murray *et al*. (1983) also found that this increased hip extension velocity began during late swing so that momentum was increased prior to contact. The purpose of this study was to measure and analyse the important angular kinematic variables in elite race walking.

METHODS: Data collection: The 7th European Cup Race Walking was held at Leamington Spa (GBR) in May 2007. Video data of the men's 50 km race and the men's and women's 20 km races were collected. Two stationary cameras (Canon, Tokyo) were placed on one side of the course. The cameras were mounted on rigid tripods and placed at approximately 45º and 135º respectively to the plane of motion. The reference volume was 5 m long, 2 m wide, and 2.16 m high; this ensured data collection of at least three successive steps and provided a calibration reference for 3D-DLT. The sampling rate was 50 Hz and the shutter speed 1/500 s. In total, twenty-nine men were analysed in the 20 km race, twenty-one in the 50 km race, and thirty women in their race. For the 20 km men, the mean age was 27 yrs (± 5) and stature 1.80 m (± .06); for the 20 km women, mean age was 26 yrs (± 5) and stature 1.64 m (± .05); and for the 50 km men, mean age was 31 yrs (± 7) and stature 1.78 m (± .08). For the men's 20 km race, analysis occurred at 8.5 km. Because the women's 20 km field was not well spread out at this point, 13.5 km was chosen instead. In the 50 km race, the men were analysed at 28.5 km.

Data analysis: The video data were downloaded and digitised to obtain kinematic data using motion analysis software (SIMI, Munich). The recordings were filtered using a Butterworth 2nd order low-pass filter and De Leva's (1996) body segment parameter models for males and females was used. Pearson's product moment correlation coefficient was used to find associations within each group of athletes. One-way ANOVA was conducted to compare values between the 20 km men, 20 km women, and 50 km men, with post hoc pairwise comparisons using Bonferroni adjustments. An alpha level of 0.05 was selected with Greenhouse-Geisser correction if Mauchly's test for sphericity was violated.

RESULTS: The average values found for speed, step length, and cadence are shown in Table 1. Step length is also expressed as a percentage of stature. The 20 km men were the fastest group, followed by the 50 km men, and then the women. Step length was significantly longer for both groups of men compared to women ($p < .01$), while cadence was significantly higher for 20 km athletes compared to the 50 km athletes ($p < .01$). Step length was correlated with speed in both groups of 20 km athletes ($p < .01$) but not in the 50 km men ($p = .14$). However, speed was correlated with step length in all groups of walkers when it was expressed as a percentage of the participants' statures ($p < .01$).

Table 1 Speed, step length, and cadence (mean ± SD)

	Speed (km/hr)	Step length (m)	Step length (%)	Cadence (Hz)
20 km Women	13.29 (± .78)	1.08 (± .05)	66.1 (± 3.2)	3.41 (± .12)
20 km Men	14.80 (± .52)	1.23 (± .05)	68.4 (± 2.4)	3.35 (± .13)
50 km Men	14.14 (± .55)	1.22 (± .06)	68.4 (± 3.4)	3.23 (± .17)

The knee angle was calculated as the angle between the thigh and leg segments. In Table 2, average absolute straightness (180°) has not been achieved in any group at initial contact. At midstance, all groups had hyperextended knees, with women having significantly greater angles than 50 km men ($p < .01$) but not 20 km men. Three athletes showed slightly flexed knees at this point (the minimum was 177°). Toe-off angles for the knee were significantly lower for 50 km men than for the other two groups ($p < .01$). Swing phase knee angle was the amount of knee flexion during swing. The women had significantly more flexion than the male groups ($p < .01$). With regard to the knee angle, the main concern of the race walker is to have it straight from contact to midstance. However, it was also found that the knee contact angle was negatively correlated with contact time in both sets of men ($p < .01$) and hence also positively with cadence ($p < .05$). There was no such correlation in women ($p = .21$). The maximum knee flexion angles found during the swing phase were correlated with speed in the 20 km women's group only ($p < .05$). The knee angle at toe-off was positively correlated with step length in both the women's and 50 km men's groups ($p < .01$).

Table 2 Knee joint angles (mean ± SD)

	Initial contact (°)	Midstance (°)	Toe-off (°)	Swing phase (°)
20 km Women	178 (± 3)	189 (± 4)	158 (± 4)	99 (± 5)
20 km Men	178 (± 3)	188 (± 3)	156 (± 3)	103 (± 5)
50 km Men	180 (± 3)	185 (± 5)	149 (± 4)	102 (± 4)

In Table 3, the figures show an average of between 9 and 13° of hip flexion at contact, and between 7 and 13° of hyperextension at toe-off. There was a significant difference in hip contact angles between 20 km men and women, and between 20 km men and 50 km men ($p < .01$). At toe-off, the hip angle was significantly larger in women than in both groups of men, and larger in 20 km men than 50 km men ($p < .01$). The hip angle at toe-off was negatively correlated with cadence in 50 km men ($p < .05$). Similarly to hip and knee contact angles, the ankle contact angle was negatively correlated with contact time and positively correlated with cadence in the 20 km men ($p < .01$). There were correlations between the ankle contact angle and that of the knee (20 km women: $p < .01$; 20 km men: $p < .01$; 50 km men: $p = .08$). In effect, those athletes with the greatest amount of knee extension had larger ankle angles.

Table 3 Hip and ankle joint angles (mean ± SD)

	Hip		Ankle	
	Initial contact (°)	Toe-off (°)	Initial contact (°)	Toe-off (°)
20 km Women	169 (± 3)	193 (± 2)	109 (± 3)	127 (± 4)
20 km Men	167 (± 4)	190 (± 2)	107 (± 3)	123 (± 4)
50 km Men	171 (± 2)	187 (± 3)	103 (± 2)	124 (± 4)

The pelvic and shoulder rotation values are shown in Table 4. The hip-shoulder distortion angle is also shown. This is the maximum amount of torsion in the trunk caused by these rotations at a given instant. The value for pelvic rotation was significantly higher in both groups of men than in women ($p < .01$) and higher in 50 km men than in 20 km men ($p < .01$). Women's shoulder rotation was higher than in both groups of men ($p < .01$) but the men's groups were not significantly different. The distortion angle was significantly lower in women than in both groups, and in 20 km men compared to 50 km men ($p < .01$). The distortion angle was correlated with step length in the women ($p < .05$), but not in either the 20 km men's group ($p = .08$) or the 50 km men ($p = .21$). Although it might be expected that the angle of the hip joint was associated with the distortion angle, there were only correlations between hip contact angle ($p < .05$) and between hip toe-off angle and distortion angle ($p < .05$) in 20 km men. The hip contact angle was positively correlated and the toe-off angle negatively correlated.

Table 4 Rotation values for the hip and shoulders (mean ± SD)

	Pelvic rotation (°)	Shoulder rotation (°)	Distortion angle (°)
20 km Women	16 (± 4)	21 (± 4)	37 (± 5)
20 km Men	24 (± 3)	17 (± 3)	40 (± 4)
50 km Men	32 (± 4)	18 (± 3)	49 (± 4)

The values for the angles of the shoulder and elbow are shown in Table 5. The shoulder was considered to be 0° in the anatomical standing position. The figures show between 68 and 77° of ipsilateral shoulder hyperextension at contact, and between 37 and 41° of flexion at toe-off. Whereas the standard deviations for the lower limb and rotation angles ranged between 2 and 5°, there was a much greater degree of variation in the values for these angles. 50 km men had a significantly greater angle at the shoulder at contact (and the elbow at toe-off) compared to both sets of 20 km walkers ($p < .01$). At contact, the elbow angle was significantly lower in women than in either group of men ($p < .01$), although the male groups were not different from each other. There were no correlations found between elbow angles and any other variables in any group. However, the shoulder contact angle was found to be positively associated with step length in the women's group ($p < .01$) and there was a tendency towards significance in the 50 km men ($p = .09$). The shoulder toe-off angle was also associated with step length in both these groups (women $p < .01$; 50 km men $p < .05$).

Table 5 Shoulder and elbow joint angles (mean ± SD)

	Shoulder at contact (°)	Shoulder at toe-off (°)	Elbow at contact (°)	Elbow at toe-off (°)
20 km Women	-69 (± 7)	41 (± 7)	71 (± 9)	65 (± 7)
20 km Men	-68 (± 7)	37 (± 5)	77 (± 8)	67 (± 5)
50 km Men	-77 (± 7)	38 (± 5)	82 (± 10)	73 (± 9)

DISCUSSION: The aim of this study was to measure and analyse the important angular kinematic variables in elite race walking. Differences were found between men and women, and between men competing over 20 km and 50 km. There were very few correlations between any angular values and the main performance variables within any single group and it is therefore difficult to ascertain which angles were particularly important. It may be that as all athletes analysed were elite, the differences that allow particular athletes to perform better are more subtle. Analysis of the angular velocities and accelerations may provide more useful information.

There were no differences in the angle of the knee at initial contact between groups, which is not surprising as athletes attempt to straighten the knee at this point. While on average the knee was not entirely extended in 20 km athletes, it may be that the knees (measured slightly below 180°) were considered straight when judged. The knee was hyperextended in all groups by midstance, as the knee was kept straightened. That only three of the eighty athletes had slight flexion at this point shows that this rule is predominantly adhered to. The correlation between knee extension angle at contact and cadence in 20 km men shows that a straight knee is not necessarily disadvantageous. However, it may have been simply the case that the walkers with the highest cadences were also the best athletes technically.

The amount of hip rotation (to the left and right) measured in women was significantly lower than in either group of men. This may be due to a lack of muscular strength in the abdominal, pelvic, and hip muscles responsible for this movement. In contrast, the women had the highest amount of shoulder rotation in counterbalancing pelvic rotation. As women had the greatest amount of hip joint hyperextension at toe-off, it is possible that this compensated for their lower levels of pelvic rotation in generating step length. The distortion angle created by the opposing movements of the pelvis and shoulders is partially what gives race walkers their distinctive gait. 50 km men had the largest amount of distortion. It may be that it is through this movement that 50km men achieve their great step lengths, as opposed to achieving them by way of the longer flight times associated with 20 km walkers.

A much greater range of values was found for the elbow and shoulder angles compared to the lower limbs. The standard deviations found for the elbow were quite large. Coaches have recommended elbow angles of approximately 90° during race walking (e.g. Markham, 1989). No group of athletes reached this value on average at either contact or toe-off, although some individuals did. Both sets of 20 km athletes had particularly low elbow angles at toe-off. It may be that these angles are of little importance or are neglected by athletes.

CONCLUSION: Most athletes in this study did conform to the straight knee rule as defined by IAAF rule 230.1. There was a great deal of variation between groups of athletes (and the individual athletes themselves) that suggests that no particular technique is optimal. Basing technical models of walking using particular walkers is unwise in developing young athletes. Recommendations for future studies include analysis of junior athletes and the changes in angular kinematics with the onset of fatigue.

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