Biomechanical analysis of elite junior race walkers

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ABSTRACT

The purpose of this study was to examine the technique of elite junior race walkers competing at the 8th European Cup Race Walking. Both the junior men's and junior women's races were videoed with two cameras placed at the side of the course where the athletes passed on every lap. Analyses of 20 competitors in each race show that stride length and stride frequency were greater in the fastest groups of athletes. Stride length differences between left-to-right and right-to-left strides were noticeable in a number of athletes and these imbalances should be rectified to improve walking efficiency and reduce risk of injury. Flight times were short in the majority of athletes and slower athletes displayed no loss of contact. Athletes were also capable of maintaining straight knees from contact to the vertical upright position. However, many athletes appeared inefficient with regard to rotational motions, with poor pelvic rotation and ungainly arm movements. Junior athletes should spend time developing their technique in order to improve efficiency, reduce the risk of injury, and lessen the chance of disqualification. Training programmes to develop both muscular power and endurance are recommended to prepare junior athletes for the demands of senior level competition.

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Introduction

There has been little research on the biomechanics of race walking in junior athletes. This is unfortunate as studies of elite junior walkers may provide a key to the development of elite senior walkers (DOUGLASS & GARRETT, 1984).

For one of the few studies available, DOUGLASS & GARRETT (1984) analysed eight international-level junior men (in two separate competitions) using one camera, operating at 48Hz, to make the recordings. The results showed that stride frequency varied very little throughout the race; instead, stride length and the ability to maintain it were the main determinants of success.

DOUGLASS & GARRETT (1984) also measured the elbow angle in six international-level junior men at both mid-stance and ipsilateral initial contact at 450m, 3250m, and 6450m approximately of a 10km race. Mid-stance elbow angles decreased from 86° at the first two measurement points (with standard deviations of 13° and 11° respectively) to 83° (± 9°) at the final point. Similarly, initial contact elbow angles decreased from 80° (± 11°) and 81° (± 13°) at the first two measurement points to 76° (± 9°). Large variations were found both between athletes and within individuals at each measurement point.

In another study on consistency, NEUMANN et al. (2008) measured variability in four junior female walkers on two separate occasions (over 6km and 10km respectively) on a treadmill. The knee angle at mid-stance showed the least variability of all variables measured, although it is highly possible that the walking speeds (slower than competition pace) were insufficient to induce significant changes. The authors also found differences between left and right legs for all four athletes tested.

HANLEY et al. (2009) used a treadmill with inbuilt force platforms and found that vertical ground reaction forces differed between senior women and junior women. The eight junior women studied displayed force patterns that resembled those of normal walking, whereas the senior women had less vertical propulsive forces. The higher vertical forces in the junior women led to a greater increase in the rise of the centre of mass, which itself led to greater loss of contact. It may be that junior athletes have not spent sufficient time developing race walking technique to optimise efficiency and reduce flight times.

The aim of this study was to analyse junior athletes competing at the 8th European Cup Race Walking held in Metz, France, in May 2009 and then use the collected data to create a database of performances and the biomechanical variables underlying them.

Methods

Two digital cameras (50Hz) were placed at the side of the course at approximately 45° and 135° to the plane of motion respectively. The reference volume was 5.2m long, 2m wide, and 2m high; this ensured data collection of at least three successive steps and provided a calibration reference for 3D-DLT. The cameras were set up at the 500m point of the 2km lap. Most athletes in both races were analysed at the 6.5km point; some athletes who were obstructed from view at this point were analysed at 4.5km instead.

Twenty athletes from both the junior men's and junior women's 10km races were analysed. In order to analyse a good distribution of finishing positions, the total number of finishers was divided by four and then five athletes were taken from each quartile. For example, there were twenty-eight finishers in the junior women's race and so five athletes from the first seven finishers have been analysed, then five from the athletes finishing 8^{th} to 14^{th}, and so on. The same approach was taken with the 39 finishers in the junior men's race. These sub-groups are referred to in this study as Top 25%, 2^{nd} 25%, 3^{rd} 25% and 4^{th} 25%.

The video data were digitised using motion analysis software (SIMI, Munich). The recordings were smoothed using a cross-validated quintic spline, and DE LEVA's (1996) body segment parameter models for males and females were used to obtain centre of mass data.

Variables of interest were defined as follows:

- Speed: the average horizontal speed during one complete gait cycle (two strides).
- Stride length: the distance the body travelled between a specific phase on one leg and the same phase on the other leg.
- Stride length difference: the difference in stride length between right-to-left and left-to-right strides.
- Stride frequency: measured by dividing horizontal speed by stride length.
- Hip / shoulder rotation: the horizontal plane movements of the pelvic girdle / shoulder girdle associated with race walking.

Definitions of specific reference points used in this study are as follows:

- **Initial contact:** the first visible point during stance where the athlete's foot clearly contacts the ground.
- **Toe-off:** the last visible point during stance where the athlete's foot clearly contacts the ground.
- **Mid-stance:** the point where the athlete's foot was directly below the body's centre of mass, used to determine the 'vertical upright position' (IAAF Rule 230.1).

Pearson's product moment correlation coefficient was used to find associations within each group of athletes. Independent t-tests were conducted to compare values between the 20 men and 20 women studied. For each variable, the data shown are the averages of left and right limb values.

Results and Discussion

The values for walking speed, stride length, stride length difference and stride frequency for men and women are shown in Tables 1a and 1b respectively. The overall average speed for the 20 men was 13.36km/hr and 11.61km/hr for the women; this difference in speed was statistically significant ($p < .01$). Walking speed is calculated as the product of stride length and stride frequency. In both sets of athletes, the highest values for these variables were found in the fastest sub-group. It was interesting to note that the respective sub-groups for men and women matched very well for stride frequency; there was no significant difference between the two groups for this variable ($p = .86$). The difference in speed between genders was therefore caused by the difference in stride length ($p < .01$).

Table 1a: Speed, stride length, and stride frequency (mean ± SD) – Junior Men

	Speed (km/hr)	Stride length (m)	Stride length difference (m)	Stride frequency (Hz)
Top 25%	14.71 (± .55)	1.22 (± .06)	0.03 (± .01)	3.35 (± .15)
2nd 25%	13.63 (± .50)	1.18 (± .07)	0.03 (± .02)	3.22 (± .17)
3rd 25%	12.89 (± .47)	1.13 (± .05)	0.03 (± .03)	3.16 (± .06)
4th 25%	12.21 (± .32)	1.09 (± .04)	0.02 (± .01)	3.11 (± .15)
Overall	13.36 (± 1.04)	1.16 (± .07)	0.03 (± .02)	3.21 (± .15)

Table 1b: Speed, stride length, and stride frequency (mean ± SD) – Junior Women

	Speed (km/hr)	Stride length (m)	Stride length difference (m)	Stride frequency (Hz)
Top 25%	12.82 (± .48)	1.07 (± .02)	0.01 (± .01)	3.34 (± .07)
2nd 25%	11.88 (± .18)	1.03 (± .03)	0.01 (± .02)	3.22 (± .09)
3rd 25%	11.25 (± .40)	0.99 (± .03)	0.02 (± .01)	3.16 (± .03)
4th 25%	10.46 (± .51)	0.94 (± .04)	0.04 (± .01)	3.09 (± .16)
Overall	11.61 (± .96)	1.01 (± .05)	0.02 (± .02)	3.20 (± .13)

The stride length difference is shown as a measure of imbalances in the athletes' walking patterns. The values given are the differences between successive stride lengths. Twelve of the men had longer strides when taking a right-to-left stride and seven had longer left-to-right strides (only one male athlete had equal stride lengths). The average difference for all the men studied was 3cm although it was as high as 7cm for one individual. With regard to the women studied, ten had longer right-to-left strides, six had longer left-to-right strides, and four had strides of equal length. The average difference for the women was 2cm, but this difference was not found to be significant ($p = .28$). Unlike the men, where there appeared to be no association with ability ($p = .85$), stride length difference was correlated with speed in the women's group ($p < .05$). In particular, the slowest sub-group of junior women had larger stride length imbalances than any other sub-group.

The stride frequency of a given athlete is dependent on the time taken for each stride. Stride time is itself dependent on the amount of contact time and flight time (if any). The values for both males and females are shown in Tables 2a and 2b. Flight times decreased as walking speeds decreased in both junior men and women. Eleven of the women and three of the men had periods of double support (i.e. no loss of contact); flight time was significantly higher amongst the male competitors compared to the females ($p < .01$). The slowest sub-group of women had no loss of contact between them, and in some cases they experienced significant periods of double support.

Table 2a: Step time, contact time, and flight time (mean ± SD) – Junior Men

	Step time (sec)	Contact time (sec)	Flight time (sec)	Contact (%)
Top 25%	0.30 (± .02)	0.26 (± .02)	0.04 (± .02)	88.0 (± 5.6)
2nd 25%	0.31 (± .03)	0.28 (± .03)	0.03 (± .02)	91.0 (± 5.8)
3rd 25%	0.31 (± .01)	0.29 (± .01)	0.02 (± .01)	93.7 (± 4.4)
4th 25%	0.32 (± .02)	0.30 (± .02)	0.02 (± .01)	93.9 (± 4.2)
Overall	0.31 (± .02)	0.29 (± .02)	0.03 (± .01)	91.6 (± 5.2)

Table 2b: Step time, contact time, and flight time (mean ± SD) – Junior Women

	Step time (sec)	Contact time (sec)	Flight time (sec)	Contact (%)
Top 25%	0.30 (± .00)	0.28 (± .02)	0.02 (± .02)	92.0 (± 5.6)
2nd 25%	0.31 (± .01)	0.30 (± .00)	0.01 (± .01)	96.3 (± 3.4)
3rd 25%	0.32 (± .00)	0.31 (± .01)	0.01 (± .01)	97.5 (± 3.4)
4th 25%	0.34 (± .02)	0.34 (± .02)	0.00 (± .00)	100.0 (± 0.0)
Overall	0.32 (± .02)	0.31 (± .03)	0.01 (± .01)	96.4 (± 4.5))

The angle of the knee joint at both initial contact and mid-stance is shown in Tables 3a and 3b. The majority of both male and female walkers studied managed to achieve full or almost full extension at initial contact. All athletes hyperextended their knees beyond 180° until after mid-stance. There was no significant difference between men and women for knee angle at contact ($p = .20$) or at mid-stance ($p = .79$). The men spent 69% of their total stance time in hyperextension and women 71%; once again there was no significant difference ($p = .56$).

The small range of values in knee joint angles at both initial contact and mid-stance is similar to the findings of NEUMANN et al. (2008) with regard to knee joint variability and is a result of repetitive training to achieve correct race walking gait.

The average values for hip and shoulder rotation within each sub-group are also shown in Tables 3a and 3b. Hip rotation is caused by the pelvis rotating forwards on the swing leg side while simultaneously rotating backwards on the stance side. Rotation of the pelvic girdle increases stride length by narrowing stride width and allowing placement of the feet closer to the line of progression (FENTON, 1984).

Apart from the relatively high values for the top male and female athletes, it was noticeable that most walkers studied had little hip rotation.

Table 3a: Knee angles and hip and shoulder rotations (mean ± SD) – Junior Men

	Knee joint		Hip and shoulder rotation	
	Contact (°)	Mid-stance (°)	Hip (°)	Shoulder (°)
Top 25%	178 (± 1)	189 (± 7)	20 (± 5)	17 (± 1)
2nd 25%	180 (± 4)	193 (± 4)	13 (± 2)	16 (± 2)
3rd 25%	181 (± 3)	192 (± 2)	12 (± 3)	18 (± 4)
4th 25%	179 (± 2)	194 (± 6)	15 (± 6)	16 (± 3)
Overall	180 (± 3)	192 (± 5)	15 (± 5)	17 (± 3)

Table 3b: Knee joint angles and hip and shoulder rotations (mean ± SD) – Junior Women

	Knee joint		Hip and shoulder rotation	
	Contact (°)	Mid-stance (°)	Hip (°)	Shoulder (°)
Top 25%	180 (± 1)	192 (± 3)	11 (± 1)	23 (± 6)
2nd 25%	180 (± 4)	192 (± 2)	8 (± 4)	19 (± 2)
3rd 25%	176 (± 3)	192 (± 5)	7 (± 2)	22 (± 3)
4th 25%	178 (± 2)	191 (± 6)	10 (± 2)	17 (± 2)
Overall	178 (± 3)	192 (± 4)	9 (± 3)	20 (± 4)

Eleven women and three men had less than 10° hip rotation. This lack of rotation can cause a reduction in overall stride length and consequently walking speed. Shoulder girdle movements occur in opposition to that of the pelvic girdle in order to counterbalance it and provide economy of movement (FENTON, 1984). Restraint of the balancing movements of the shoulder girdle leads to an inability to progress in a straight line at higher speeds and to increased energy expenditure (INMAN et al., 1981). Rotation of the shoulder girdle was greater in most competitors than the hip rotation it was acting to counterbalance. Overall, the men had significantly greater pelvic rotation ($p < .01$) while the women had significantly greater shoulder girdle rotation ($p < .01$).

The forward and backward movements of the arms in race walking act to balance the body by counteracting the opposing movements of the legs. The amount of arm motion can be measured by quantifying the angle of the shoulder joint. Tables 4a and 4b show the shoulder joint angles at both contact and toe-off. The contact values are shown as negative values to signify their hyperextended position (the larger the value, the further back the arm). At toe-off the arm is in front of the body and in most cases the hand came close to the body's midline. It is clear from the results that the fastest sub-group of the men had the largest amount of shoulder movement at both contact and toe-off (and hence the largest

Table 4a: Shoulder and elbow joint angles (mean ± SD) – Junior Men

	Shoulder joint		Elbow joint	
	Contact (°)	Toe-off (°)	Contact (°)	Toe-off (°)
Top 25%	-70 (± 8)	41 (± 7)	89 (± 14)	70 (± 12)
2nd 25%	-63 (± 8)	37 (± 7)	82 (± 9)	73 (± 8)
3rd 25%	-63 (± 5)	36 (± 8)	69 (± 8)	68 (± 9)
4th 25%	-63 (± 7)	32 (± 6)	80 (± 15)	73 (± 13)
Overall	-65 (± 7))	37 (± 7)	80 (± 13)	71 (± 10)

Table 4b: Shoulder and elbow joint angles (mean ± SD) – Junior Women

	Shoulder joint		Elbow joint	
	Contact (°)	Toe-off (°)	Contact (°)	Toe-off (°)
Top 25%	-65 (± 6)	39 (± 5)	68 (± 10)	65 (± 3)
2nd 25%	-61 (± 4)	34 (± 7)	64 (± 10)	66 (± 7)
3rd 25%	-68 (± 6)	36 (± 6)	63 (± 9)	66 (± 6)
4th 25%	-71 (± 6)	34 (± 10)	79 (± 13)	73 (± 7)
Overall	-66 (± 7)	36 (± 7)	68 (± 12)	67 (± 6)

range of motion). Significant correlations were found among the men between stride length and shoulder contact angle ($p < .05$) and stride length and shoulder toe-off angle ($p < .01$).

There were no apparent patterns (nor significant correlations) with regard to overall range in the women's race, although the fastest subgroup did have slightly larger shoulder angles at toe-off. The overall values for men and women did not differ significantly from each other (at contact, $p = 0.51$; at toe-off, $p = 0.69$). Tables 4a and 4b also show the results for elbow flexion at both initial contact and toe-off. The average elbow angle for men at contact was 80°, which was significantly greater than the average value of 68° for women ($p < .01$). This angle changed little for the women athletes by the point of toe-off, but decreased by 9° for the men, resulting in no significant difference in values at toe-off ($p = .17$). Similarly to the findings of DOUGLASS & GARRETT (1984), there was a much larger range of values for the elbow joint than any other joint measured. While a certain degree of variation is normal when considering different statures and builds, it was nonetheless evident from watching the video recordings that many athletes had excessive arm movements, which appeared ungainly and inefficient.

Recommendations

One of the key concerns of junior athletes and their coaches is how to develop into a successful senior athlete. This is particularly important in race walking, as there is an increase in competitive distance to 20km (and also 50km for men). This increase can be difficult for many athletes, and the transition requires a comprehensive understanding of the biomechanical strengths and weaknesses of each individual.

The present study shows that slower athletes had both shorter stride lengths and lower stride frequencies. Stride length can be improved by increasing the strength and flexibility of the trunk and thigh muscles so that greater pelvic rotation is achieved. The muscular power of the hip and ankle muscles should be developed to improve both stride length and frequency. These can be achieved at first by means of strength and conditioning training which emphasises all the major muscle groups (i.e. abdominals, back, hips, legs, shoulders, arms) to ensure competency in functional movement and to reduce the risk of injury. The development of the power of these muscle groups will lead to shorter contact times and quicker swing times. It should also always be remembered that race walking is an endurance event, so strength training programmes should be developed with muscular endurance in mind, e.g. via circuit training. With regard to stride duration, several women in particular had comparatively long periods of double support. These contact times could be shortened to improve the rate of stride frequency while still retaining a period of double support.

Several of the athletes we studied displayed imbalances between strides with regard to length. If possible, coaches should measure athletes' individual stride lengths and attempt to reduce left / right imbalances in order to improve efficiency and reduce the risk of injury. There can be different causes of such imbalances, such as weak muscular development or poor flexibility on one side of the body; in a sense, the stronger side may be 'carrying' the other. The cause may be due to inadequacies in technique, which must be removed before the athlete attempts to move up to the longer senior distances. Functional movement and musculoskeletal screening tests may be warranted for these athletes, led by strength and conditioning coaches and physiotherapists working together with the athlete and coach.

It cannot be stressed enough that correct technique training must be emphasised throughout a junior athlete's development. Juniors cannot be expected to match senior athletes with regard to training loads (e.g. total yearly distance walked). However, time can be spent on ensuring compliance with the two specific rules of race walking with regard to loss of contact and knee straightening. Of the athletes who competed in the races we analysed, four men and four women were disqualified.

It is not sensible for a junior athlete to attempt competing over 20km if he or she is unable to comply with the rules to the satisfaction of the judges (who will see the athlete twice as often as in a 10km race). Avoiding loss of visible contact and straightening the knee are skills, which fortunately can be learned through repeated practice of correct technique.

Although there is no proposed ideal range of movement for the shoulder and elbow to move through, it was clear that many of the athletes studied had excessive and inefficient movements at the shoulder. The shoulder joints function in race walking to balance the forward-backward movements of the legs; athletes should attempt to allow their shoulders and arms to swing following the legs' natural rhythm. The elbow angle appears to be associated with the athlete's standing height but it is still recommended that walkers try to maintain a relaxed elbow position.

Biomechanical variables are not the only factors that require attention. VALLANCE (2007) suggested that underlying aerobic qualities and a particular psychological mindset are required to develop junior walkers over 10km into senior walkers over 20km. He also stated that it is important for the athlete to replicate the requirements of the longer event in training.

One of the aims of this study was to collect data on junior athletes in order to create a database of performances and the biomechanical variables underlying them. Future analyses of these athletes as they mature will allow us to follow their development and identify patterns that indicate how junior athletes manage the transition to senior competition.

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