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# Biomechanical Analysis of Leg Asymmetry in Young International Race Walkers

by Brian Hanley and Athanassios Bissas

## ABSTRACT

*The purpose of this study was to measure kinetic and kinematic variables as well as muscular activity in young international race walkers to observe any possible leg asymmetry. Five men and three women race walked on an instrumented treadmill for 3km and kinetic and kinematic data were collected at the halfway distance. The activity of four muscles on each leg was simultaneously measured using electromyography. Similar to previous findings of elite junior race walkers in competition, half of the athletes had stride length differences, but imbalances in other variables were less common. In particular, vertical ground reaction force peaks were very similar between legs. However, the electromyography findings showed that some of the athletes had substantial differences between leg muscles with regard to activation levels, and that compensation occurred between synergist muscles (gluteus maximus and biceps femoris) within the same leg. Coaches are advised to closely monitor the technical and strength development of their young athletes to ensure that both sides of the body are balanced. This is especially important with regard to preventing injury, maximising efficiency, and reducing the risk of disqualification.*

## AUTHORS

*Brian Hanley, BSc, is a Senior Lecturer in Sport & Exercise Biomechanics, in the Carnegie Faculty at Leeds Metropolitan University in Great Britain where he is working towards a doctorate.*

*Athanassios Bissas, PhD, is a Principal Lecturer in Sport & Exercise Biomechanics, in the Carnegie Faculty at Leeds Metropolitan University in Great Britain.*

## Introduction

Race walking is primarily an endurance event demanding a considerable level of cardiovascular fitness. However, as in all other athletics events, competitors also require appropriate levels of muscular strength and conditioning. Because of its rules, race walking requires the athlete to use a unique form of gait and therefore strength training needs to be based on the specificity of the movements involved and orientated towards maintenance of technique[1], with the development of all-round strength and endurance a necessity[2]. In particular, it is important for race walkers to ensure both sides of the body are equally well trained to optimise performance and avoid disqualification.

In a previous study on elite junior race walkers in competition[3], it was found that many of the athletes had different left-to-right and right-to-left stride lengths. It was suggested at the time that weak muscular development or poor flexibility on one side of the body could be a cause of these imbalances. In following up those findings, the aim of the present laboratory study was to measure kinematic and kinetic variables in young race walkers to see if any differences were present, to measure the muscular activity in particular leg muscles important in race walking in order to detect any imbalances.

## Methods

Eight young international race walkers gave informed consent and the Leeds Metropolitan University Ethics Committee approved the study. Five of the athletes were male (height 1.75m (± .04), mass 67.0kg (± 5.2)) and three were female (height 1.68m (± .08), mass 52.9kg (± 5.5)). For the purposes of this study, men's and women's results have been grouped together. The group included athletes who had participated at competitions such as the IAAF World Junior Championships, IAAF World Youth Championships, and European Athletics Junior Championships. All participants were free from injury. Each athlete walked for 3km on a treadmill (Gaitway, Traunstein) at a constant pace equivalent to 95% (± 2) of their season's best for 10km.

Kinetic data were recorded using the treadmill, which has two in-dwelling force plates (Kistler, Winterthur). Data were collected for thirty seconds at 1500m at a sampling rate of 1000Hz. This resulted in analysis of between 90 and 100 strides per athlete. The Gaitway software produced average data for important vertical ground reaction force (GRF) variables such as impact and propulsive forces. In order to account for the different body masses of the walkers, all GRF data were normalised and hence have been presented in this study in bodyweights (BW). As well as GRF data, the associated software gave values for kinematic data (e.g. stride length) and temporal data (e.g. stride time). High-speed cameras (250Hz) were positioned in front, behind, and to the side of the treadmill in order to provide videos for qualitative analysis.

Electromyography (EMG) is used to record changes in the electrical potential of a muscle when it contracts and offers the only method of objectively assessing when a muscle is active[4]. Surface EMG signals were recorded from four lower limb muscles of both left and right legs: gluteus maximus (GM), biceps femoris (BF), vastus lateralis (VL), and gastrocnemius (lateral head) (GL). Skin preparation involved cleansing of the skin with alcohol swabs[5] and shaving to remove any hair. The single differential electrodes (DelSys, Inc., Boston) consisted of two silver bars 10mm long, 1mm wide, and 10mm apart set in a rectangular polycarbonate casing. The reference electrode was placed over the fourth lumbar vertebra. After identifying the appropriate attachment sites by palpating the contracted muscle, each electrode was placed over the muscle belly, aligned parallel to the underlying muscle fibre direction[6]. A telemetry unit (DelSys, Inc., Boston) was used to collect the data at 1000Hz. To ensure low levels of movement artefact, wires connecting the electrodes to the unit were kept in place with tubular elastic net bandages. EMG data collection lasted five seconds and recorded for approximately seven strides on each leg. The raw EMG signals were processed using average rectified EMG (AREMG), with a time window of 50 milliseconds and an overlap of 25 milliseconds.

Variables of interest were defined as follows:

**Speed** - the average horizontal speed during each complete gait cycle (two strides). Race walking speed is the product of stride length and stride frequency.

**Stride length** - the distance the body travelled between a specific phase on one leg and the same phase on the other leg.

**Stride length ratio** - stride length expressed as a percentage of standing height.

**Stride length difference** - the difference in length between right-to-left and left-to-right strides. Stride lengths less than 1cm different were considered to be of equal length.

**Stride frequency** - the number of strides taken per second, measured in Hz.

**Stride width** - a measurement of how closely the feet followed a straight line as the athlete walked.

**Progression angle** - a value that indicated whether the foot was turned inwards (a negative value) or outwards (a positive value) during stance.

**Impact force** - the initial force that the athlete experienced at first contact (within the first 0.07 sec of stance).

**Loading peak force** - the maximum force measured when the athlete's weight loaded the stance foot.

**Mid-stance force** - the force experienced at the 'vertical upright position' (IAAF Rule 230.1).

**Push-off peak force** - the maximum amount of force the athlete used to push-off prior to toe-off.

## Results

The mean values for speed and all stride length values for the eight race walkers are shown in Table 1. Stride length ratio, which has been found to be more important than absolute stride length (in metres) for optimal race walking performances[7], ranged between 59 and 63%. The average stride length difference was just over one centimetre, but there was some variation between athletes. Four of the race walkers had no stride length difference and of the other four athletes, the largest differences were 2cm for two males and 3cm for one female.

Mean temporal and foot positioning values are shown in Table 2. Stride time is the reciprocal of stride frequency. Because of the interrelationship between stride length and stride frequency, there were also differences between right and left legs for stride time, but these were quite short with an average difference of 0.007 sec (± .005). The average stride width was relatively narrow at only 4cm. The average progression angle was a negative value as five of the participants turned both left and right feet inwards, and the other three all turned their left leg inwards and their right foot outwards.

The mean values of the vertical GRF variables are shown in Table 3. Of the four force

*Table 1: Speed and stride length variables (mean ± SD)*

| Speed (km/hr) | Stride length (m) | Stride length ratio (%) | Stride length difference (cm) |
|---|---|---|---|
| 11.85 (± .48) | 1.07 (± .05) | 61.0 (± 1.3) | 1.1 (± 0.9) |

*Table 2: Temporal and foot positioning variables (mean ± SD)*

| Stride frequency (Hz) | Stride time (sec) | Stride width (cm) | Progression angle (°) |
|---|---|---|---|
| 3.08 (± .12) | 0.325 (± .012) | 4.0 (± 1.1) | -3.9 (± 5.5) |

*Table 3: Ground reaction force variables (mean ± SD)*

| Impact force (BW) | Loading peak force (BW) | Mid-stance force (BW) | Push-off peak force (BW) |
|---|---|---|---|
| 1.21 (± .35) | 1.80 (± .13) | 1.50 (± .15) | 1.59 (± 0.8) |

variables measured, impact peak showed the greatest difference between left and right legs (0.28BW ± 0.20). The loading force was the highest peak measured in all eight race walkers. On average, the mean mid-stance force was slightly lower than the push-off peak force, but in three male individuals the opposite occurred and the push-off peak was smaller than the mid-stance force. With only a few individual exceptions, loading peak force, mid-stance force and push-off peak force values were very similar between left and right legs (within 0.10BW).

The EMG traces were analysed in order to identify any differences between left and right leg muscles. The traces were adjusted so that the timings of initial contact and toe-off in each leg were synchronised to facilitate comparisons between them. The swing phase lasted approximately 54% of the gait cycle and the stance phase the remaining 46%. In general, the muscles on both sides of the body were balanced in all athletes in terms of activation levels and timings (especially the gastrocnemius muscles). There were however some striking exceptions. Two of the male walkers had considerable differences between the activation levels of the right and left vastus lateralis muscles during the contact phase (the EMG trace of three strides of one of these athletes is shown in Figure 1 as an example). In addition, it was noticed that several athletes compensated for a lack of activity in a particular muscle with increased activity in a synergist muscle (i.e. gluteus maximus and biceps femoris). An example of this is shown in Figures 2 and 3, where the EMG of one athlete during a single stride has been presented to highlight this phenomenon. In Figure 2, it can be seen that both right and left gluteus maximus muscles contracted prior to contact (between approximately 20 and 50% of the gait cycle). However, during stance, the left gluteus maximus was active in extending the hip between 50 and 80% whereas right gluteus maximus activity was much quieter during the same phase. In Figure 3, the opposite occurred, and the right biceps femoris was noticeably active during the first half of the stance phase whereas the left biceps femoris was not (there was no substantial difference between the right and left biceps femoris muscles during the earlier swing phase).

## Discussion and Recommendations

The purpose of this study was to measure kinematic and kinetic variables and muscle activity in young race walkers to detect if leg asymmetry was present. The average walking speed in this study was lower than that normally walked by the athletes in competition due to testing taking place early in the training year. As a result, the values measured in this study for key variables such as stride length and stride frequency were slightly lower than those found in elite junior race walkers in competition[3]. Similarly, stride length ratio was shorter than that found in elite senior athletes[7] and this is therefore an important variable for these junior athletes to develop. Of course, the advantage of this early season testing for these particular athletes was that any potential problems were discovered before serious training and competition commenced. In particular, the differences in stride length and stride time that were found in some athletes might have increased in high-level competition if not dealt with. The narrow stride width observed was an indicator of good race walking technique but some athletes achieved it by turning their feet inwards too much. This unnatural placement of the feet can strain the muscles on the lateral side of the leg and lead to injury. This technical error can occur because of weak hip muscles which do not control inward rotation of the leg nor generate sufficient pelvic rotation. Athletes should therefore take care that training and competition are not undertaken with incorrect technique which could increase the risk of injury.

In terms of the overall kinetic findings, the average impact peak measured in this study was much lower than that found typically in distance running[8] and impacts of this magnitude are unlikely to result in injury. In experienced race walkers, the loading peak force is greatest, followed by a slightly lower mid-stance force and an even lower push-off

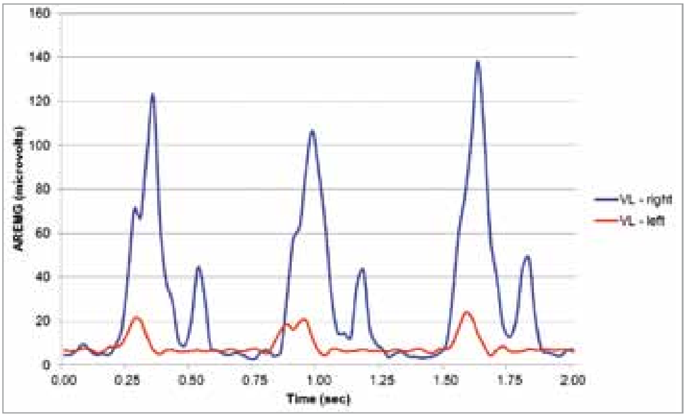


*Figure 1: Right and left vastus lateralis EMG activity during three successive strides in one athlete*

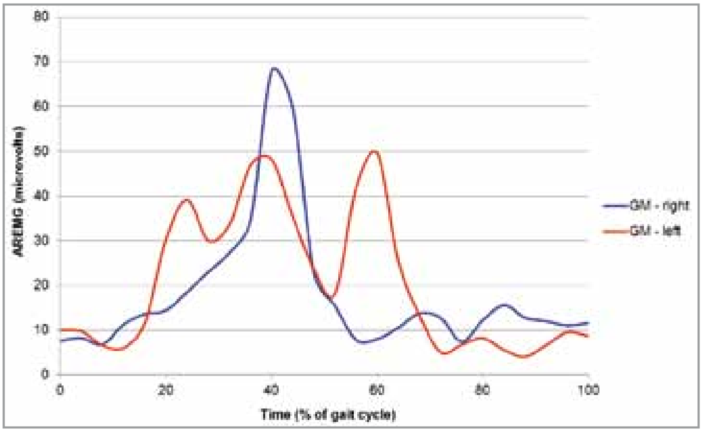


*Figure 2: Right and left gluteus maximus EMG activity during a single stride in one athlete*

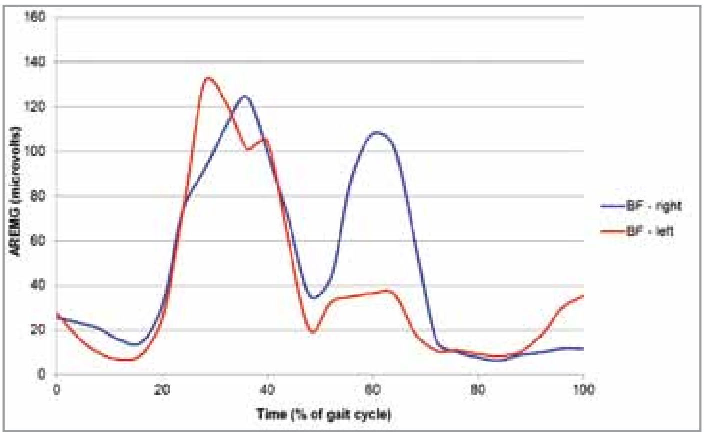


*Figure 3: Right and left biceps femoris EMG activity during a single stride in one athlete*

peak force[9]. This is in contrast to normal walking where the push-off peak force is roughly equal to the loading peak force[10]. The different pattern in race walking is due to the need to avoid too much vertical propulsion and a consequential visible loss of contact. Achieving this highly efficient movement pattern requires many years of practising correct race walking technique and can therefore be considered a 'mature' race walking gait. Of the eight walkers tested, only three of these young athletes (who were all male) demonstrated a mature gait of this nature. While a positive finding was that most athletes had few differences between the legs for vertical GRF values, larger differences could result as the walkers progress to senior competition and greater training volumes. Because of this, regular monitoring of the athlete's technique by the coach is required to ensure that both sides of the body move efficiently.

Correct technique is also important in terms of satisfying the two specific rules of race walking. With regard to the requirement for a straightened knee from first contact until the vertical upright position, an athlete can be disqualified if either knee is bent so it is clearly important that both legs are well trained. Some athletes do not require large amounts of muscle activity in order to achieve a straightened knee if, for example, they have a highly mobile knee joint. This was seen in most of the athletes in this study as there was little activity in the vastus lateralis, a knee extensor which forms part of the quadriceps femoris muscle group on the anterior thigh. However, two of the men did display high levels of vastus lateralis EMG activity, but in both cases this was evident in one leg only (Figure 1). This might have been due to a lack of mobility around the knee joint, which is often caused by a lack of flexibility in the antagonist hamstring muscles. An athlete who must forcibly use their quadriceps muscles to straighten their knee on every stride expends considerable energy. This can therefore result in local muscular fatigue in competition, increasing the risk of disqualification in the latter stages of the race.

Gait movements can be achieved in a number of ways, and if a particular muscle cannot be used, its function can be taken over by another muscle or muscle group[10]. However, if stronger muscles repeatedly compensate for weaker ones imbalances and injury can occur, especially if these result in one side of the body compensating for the other. It was interesting to note that in some cases there were compensations not just between muscle groups, but within legs as with the highlighted example of the biceps femoris and gluteus maximus (Figures 2 and 3). The role of the hamstrings during race walking is significant because they serve to decelerate hip flexion and knee extension during mid-swing, and to extend the hip during late swing until mid-stance. If large, powerful muscles such as gluteus maximus do not contract during these phases, the hamstrings must take the full strain involved in these rapid movements. In the short term (e.g. during a competition), this could result in early muscle fatigue, and in the long term, injury. Indeed, Francis et al.[11] found that the most commonly reported injuries in race walking were to the hamstrings. Hamstring injuries are also common in competitive running and sports involving fast running due to the similar eccentric contractions that occur during swing[12]. In this study it was interesting that although the hamstrings were overused in some instances, the opposite was also true in other cases where the hamstrings were underused and the gluteus maximus assumed the entire hip extensor role instead. What is therefore clear is that race walkers and their coaches should monitor the strength of individual muscles and muscle groups to make sure particular muscles are working to the required level and at the correct times during the gait cycle.

## Conclusion

Kinematic, kinetic and EMG measurements conducted on a competitive group of young walkers revealed a number of imbalances between legs, although for the most part these differences were quite small. Leg asymmetry can occur due to a variety of reasons, such as a lack of joint mobility or muscle strength on one side of the body. While it was easy to identify the importance of differences in some key race walking variables, such as stride length, the factors that might underlie these variables were more subtle and less easy to evaluate. Athletes who do not display imbalances externally (such as differences in stride length) might still exhibit internal imbalances, and because of this all-round technical and strength development must be very carefully monitored. The time spent developing efficient and correct technique in junior athletes is worthwhile preparation for senior competition over the longer distances of 20 and 50km.

**Please send all correspondence to:**

*Brian Hanley*

*b.hanley@leedsmet.ac.uk*

## REFERENCES

1. SCHOLICH, M. (1992). Why technique oriented strength development for race walkers? Modern Athlete and Coach 30 (4): 27-29.

2. HADRYCH, R. & SCHROTER, G. (1980). All-round development a must for young walkers. Modern Athlete and Coach 18 (2): 33-34.

3. HANLEY, B.; BISSAS, A. & DRAKE, A. (2010). Biomechanical analysis of elite junior race walkers. New Studies in Athletics 25 (2): 39-47.

4. BARTLETT, R. (2007). Introduction to Sports Biomechanics (2nd ed.). London, E&FN Spon, 258-272.

5. OKAMOTO,T.; TSUTSUMI, H.; GOTO, Y. & ANDREW, P.D. (1987). A simple procedure to attenuate artifacts in surface electrode recordings by painlessly lowering skin impedance. Electromyography and Clinical Neurophysiology 27 (3): 173-176.

6. CLARYS JP, CABRI J. Electromyography and the study of sports movements. Journal of Sports Sciences 1993; 11 (5): 379-448.

7. HANLEY, B.; BISSAS, A. & DRAKE, A. (2011). Kinematic characteristics of elite men's and women's 20 km race walking and their variation during the race. Sports Biomechanics 10 (2): 110-124.

8. NOVACHECK, T.F. (1996). The biomechanics of running. Gait and Posture 7 (1): 77-95.

9. HANLEY, B.; DRAKE, A. & BISSAS, A. (2009). The measurement of kinetic variables in race walking. In Harrison, AJ, Anderson, R, Kenny, I. (eds) Procedings of the XVIII International Symposium in Sports, 685-688.

10. WHITTLE, M.W. (1996). Gait Analysis: an introduction (2nd ed.). Oxford, Butterworth-Heinemann, 53-107.

11. FRANCIS, P. R.; RICHMAN, N.M. & PATTERSON, P. (1998). Injuries in the sport of racewalking. Journal of Athletic Training 33 (2): 122-129.

12. CHUMANOV, E.S.; HEIDERSCHEIT, B.C. & THELEN, D.G. (2011). Hamstring musculotendon dynamics during stance and swing phases of high-speed running. Medicine and Science in Sports and Exercise 43 (3): 525-532.