BIOMECHANICAL PERFORMANCE FACTORS
IN POSE RUNNING AND HEEL-TOE RUNNING

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Abstract

The aim of this paper is to identify known biomechanical performance factors between ten experienced Pose runners and ten experienced Heel-toe runners. Both groups of experienced runners were compared using nine kinematic variables. The Pose Group showed a distinct biomechanical profile and was significantly different from the Heel-toe Group. Known biomechanical performance factors were identified in the Pose Group for lower vertical oscillation, a more vertically aligned body at impact with a shorter step length but a higher step frequency. Stance time and knee extension during stance were lower while knee flexion angular velocity during swing was higher. These findings should enable coaches to identify performance factors for each running group. Further work should identify injury incidence between the two running techniques.

Key words: running technique, running style, kinematic

Introduction

A clear method for teaching running would be advantageous. However, for effective teaching there needs to be a clear biomechanical profile that underlies any running technique. For example, elite runners do not exhibit a consistent biomechanical profile that could be prescribed as ideal (Cavanagh et al., 1985). Therefore a universal standard of what is ‘good’ technique needs identifying in order to make authoritative recommendations when teaching or coaching. Presently running technique is determined by foot contact, where 80% of endurance runners impact the ground heel first and 20% impact on the forefoot (Kerr et al., 1983; Whittle, 1991). Heel-toe running is therefore the norm in endurance running. However, a novel technique Pose running (Romanov and Fletcher, 2007) is based on a more comprehensive biomechanical profile than only foot contact.

Pose running is based upon a whole body Pose that vertically aligns the shoulder, hip and ankle of the support leg, while landing with the weight on the ball of the support foot (figure 1). The runner then moves from this Pose on one leg to the other by potentially falling forward via a gravitational torque (Romanov and Fletcher, 2007). The runner is taught to pull the support foot vertically upwards from the ground using the hamstring muscles as the body falls forward, while the ipsilateral leg is not driven forwards during flight but allowed to fall to the ground via gravity to land in the next running Pose (Romanov and Fletcher, 2007).
Arendse et al. (2004) recorded Heel-toe runners in their customary Heel-toe condition at 2.98 ± 0.42 m/s and then immediately afterwards asked them to run on their forefoot (3.06 ± 0.42 m/s). The participants were then tested again in their barefoot condition at 2.90 ± 0.37 m/s following a five day Pose (total seven hours) running intervention. Their Pose condition was significantly different from their Heel-toe and Forefoot conditions for step length and step frequency. However, barefoot running has been shown to differ from shod (wearing shoes) for example, just before impact, shod runners increase knee flexion velocity while eliciting a shorter stance time (Clarke et al., 1983; De Wit et al., 2000). It was suggested by Arendse et al. (2004) that future research should investigate technique differences based upon a whole body approach with shod runners, which this paper seeks to accomplish.

Heel-toe and Pose runners were investigated for whole body differences after a twelve-week Pose running intervention consisting of a single one-hour lesson per week (Dallam et al., 2005). Kinematic data was collected at 120 Hz in 2-D pre and post intervention on a treadmill at their lactate threshold running speed. Their study identified that stride length and vertical oscillation decreased in the Pose Group. However, a limitation of the study was a treadmill affects Pose running because the axis of rotation changes from the foot in over-ground running to the hip in treadmill running (Zatsiorsky, 1995). The treadmill also pulls the foot backwards whereas in Pose running the foot needs to be pulled upwards (Romanov and Fletcher, 2007). Further, the kinematic data was collected in an extremely fatigued state. A maximal oxygen uptake test, lactate threshold and economy run where administered making it questionable the Pose Group were able to maintain their newly learned technique (Fitts and Posner, 1967). Therefore, potential whole body kinematic differences between Pose and Heel-toe running warrant further investigation using over-ground running in a non-fatigued state.

Certain biomechanical factors have been identified with improved running performance. Morgan et al. (1994) recording freely chosen stride frequency and stride length found 20% of their participant pool had over-striding patterns. By reducing these participant’s stride lengths they improved their performance measured as reductions in oxygen consumption. Further, taking shorter stride lengths has been associated with less muscle soreness in downhill running a major component of cross country running and road racing (Rowlands et al., 2001). Lower vertical oscillation has been associated with better runners (Williams and Cavanagh, 1987) based on the premise that completing less vertical work will improve performance (Novacheck, 1996). Reduced support time is associated with improved performance (Paavolainen et al., 1999). They suggested muscle stiffness and utilisation of muscle elasticity during the stretch-shortening cycle might account for the improved performance from shortened contact times. The centre of mass landing in closer vertical alignment with the support foot at impact is a clearly established performance factor for faster runners (Fenn, 1930; Deshon and Nelson,
1964; Bates et al., 1979; Girardin and Roy, 1984; Hinrichs, 1990; Kong ad de Heer, 2008). Other measures have been associated with improved performance but were not measured in this study: Williams and Cavanagh (1987) found runners with a mean forward trunk lean, relative to the vertical axis, more economical at 5.9° compared with 3.3° and 2.4°.

From a coaching perspective a clear kinematic profile is more helpful than use of kinetic measures. Therefore, the aim of this paper is to establish a full body kinematic biomechanical profile for Pose running and then to determine which technique (Pose or Heel-toe) has biomechanical factors that are associated with increased running performance.

Methods

Ten experienced males in Pose running formed the Pose Group and ten experienced runners in Heel-toe running made up the Heel-toe Group for this study (table 1). Written informed consent and ethical approval from Sheffield Hallam University were obtained. All participants had no history of surgical intervention, chronic pain, orthotic use or current pathology of the lower extremity. Each participant wore his normal running shoes. All shoes were qualitatively assessed for rigidity of the Heel counter and compliance of the cushioning element of the rear section of the shoe.

**Table 1.** The participant’s characteristics for the Heel-toe and Pose runners ($N = 20$)

<table>
<thead>
<tr>
<th></th>
<th>Pose</th>
<th>Heel-Toe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass (kg)</td>
<td>77.5 ± 6.1</td>
<td>76.1 ± 0.7</td>
</tr>
<tr>
<td>Body Height (cm)</td>
<td>180.8 ± 5.0</td>
<td>180.5 ± 78.7</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>26.9 ± 11.6</td>
<td>24.9 ± 9.6</td>
</tr>
<tr>
<td>10-km Personal best (min)</td>
<td>40.4 ± 3.7</td>
<td>39.0 ± 3.7</td>
</tr>
</tbody>
</table>

Experimental protocol

All participants were pre-selected before the testing date through personal contact. All respondents were selected based on the following criteria: 1) they had been without injury in the past 12 months, 2) were male, 3) competitive athletes and 4) were experienced in their respective running techniques and were similar in age, experience, stature and weight (table 1). Each participant completed an individual warm up and then ran on a 15.66 m runway at 3.35 m/s where kinematic data were recorded. The runway was the total length of the biomechanics lab.

Collection and processing of kinematic data

A modified Helen Hayes marker set (22-markers) was used to collect their three-dimensional trajectories for computing kinematic data. Retroreflective spheres of a diameter of 2 cm (4.4 g) were applied to the subject’s bodies in order to define a model comprised of twelve body segments: two segments for feet, lower legs, upper legs, forearm, upper arm and two single segments comprising the head/neck and trunk. These markers were applied directly onto the skin using athletic tape on the acromion processes, elbow and radiocarpal joints, sacrum, anterior superior iliac spines, lateral femoral condyles, lateral malleolus, and the dorsim of the feet between the second and third metatarsals. Two lateral wands were used to calculate the medial knee and ankle markers during the dynamic trials. The two lateral wands were 10 cm long and attached using athletic tape to the thigh, midway between the hip and knee joints, and
for the shank, midway between the knee and ankle joints. Both wands were vertically aligned with the relevant joints. An off-set marker placed on the right scapula precipitated software marker recognition through body asymmetry. Video data were collected using a VPAT 310 video recorder and an eight-camera (Falcon HR 240) motion analysis system recording at 120 Hz (Motion Analysis Corporation, Santa Rosa, California) which collected data for one step of the right leg while running in the positive X direction. The cameras were zoomed in as far as possible to a volume of 3.6 m in x (fore-aft axis) by 1.4 m in y (medio-lateral axis) and 2 m in z (vertical axis) with the centre of the base corresponding to the centre of the force plate. The laboratory (global) orthogonal coordinate system followed the right hand rule and had the positive x-direction orientated in the direction of forward progression, the positive y-direction orientated to the left and the positive z-direction orientated vertically upward. The volume was calibrated before data collection using a cube and a 500 mm wand associated with EvaRT 3.2 data collection software (Motion Analysis Corporation, Santa Rosa, California). During data collection, the experienced Heel-toe Group and Pose Group ran at 3.35 m/s. Running speeds were measured by two photoelectric cells 4.19 m apart and 3 m from the centre of the force plate, and mounted so the participant’s waist triggered the photoelectric cells. Up to five trials were recorded at each speed, while three trials in which ‘good’ foot contact with a steady stride and speeds within 5% of the measured speed were analysed. The three dimensional coordinate data were filtered using a 2nd order low-pass Butterworth filter; a cut-off frequency of 6-8 Hz was used and was selected through visual inspection of the fit (Winter, 1990). Video and analogue data were time synchronised using impact, recorded when vertical ground reaction force exceeded 20 N. Following the filtering process in EvaRT 3.2, the filtered video data were extracted using OrthoTrak 5 software. Coordinate and angular data were calculated from the filtered raw data (Winter, 1990).

Statistical analysis

Nine variables were selected for statistical analysis (table 2) that kinematically describes the Pose Group (Romanov and Fletcher, 2007). The two groups of ten participants each were then compared using two-tailed independent t-tests. The probability level was corrected according to the Bonferroni adjustment from $p < 0.05$ to $p < 0.0055$ (0.05 / 9). Effect sizes were calculated (Rosnow and Rosenthal, 2005) with a large effect taken for $r > .5$ (Cohen, 1988). All statistical calculations were performed using SPSS 15.00 (SPSS, Inc, Chicago, IL).

Results

Figure 2 shows a typical Pose runner and a Heel-toe runner at key points during the gait cycle. Note the more aligned body of the Pose runner at impact and less knee extension at terminal stance.

![Figure 2](image)

Figure 2. a) Typical Pose runner and b) Heel-toe runner at impact, mid-stance and terminal stance.
Table 2 shows both the Heel-toe Group and Pose Group’s full body data (means and standard deviations). Significant differences between the two running techniques are evident. Average horizontal velocity for the centre of mass during stance (displacement divided by stance time) were similar for the Pose Group and Heel-toe Group respectively at 3.44 and 3.45 m/s. Lower vertical oscillation coupled with lower knee extension were identified in Pose Group (Wank et al., 1998). Shoulder, hip and ankle vertical alignment at 25 ms of stance showed a more aligned body in the Pose Group. Knee flexion angular velocity for swing, was taken from the last frame after terminal stance until mid-swing and was higher in the Pose Group while knee flexion and extension during stance were less. All measured variables show large effect sizes.

Table 2. A comparison of the research variables between Heel-toe and Pose running ($N = 20$)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pose</th>
<th>Heel-toe</th>
<th>$P$-value</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stance time (ms)</td>
<td>0.21 ± 0.01</td>
<td>0.25 ± 0.01</td>
<td>0.002</td>
<td>.84</td>
</tr>
<tr>
<td>Body’s centre of mass horizontal displacement stance (cm)</td>
<td>72.2 ± 5.3</td>
<td>87.4 ± 6.4</td>
<td>0.001</td>
<td>.87</td>
</tr>
<tr>
<td>Knee flexion stance (rad)</td>
<td>0.41 ± 0.01</td>
<td>0.58 ± 0.04</td>
<td>0.001</td>
<td>.86</td>
</tr>
<tr>
<td>Knee extension stance (rad)</td>
<td>0.46 ± 0.2</td>
<td>0.69 ± 0.1</td>
<td>0.04</td>
<td>.68</td>
</tr>
<tr>
<td>Knee flexion angular velocity from terminal stance until mid-swing (rad.s$^{-1}$)</td>
<td>7.8 ± 1.0</td>
<td>6.1 ± 0.9</td>
<td>0.04</td>
<td>.67</td>
</tr>
<tr>
<td>Shoulder, hip ankle vertical alignment at 25 ms of stance (cm)</td>
<td>7.4 ± 3.1</td>
<td>14.1 ± 4.9</td>
<td>0.05</td>
<td>.66</td>
</tr>
<tr>
<td>Vertical oscillation of the body’s centre of mass (cm)</td>
<td>9.1 ± 0.8</td>
<td>11.6 ± 1.4</td>
<td>0.01</td>
<td>.77</td>
</tr>
<tr>
<td>Step length (cm)</td>
<td>117.2 ± 8.9</td>
<td>132.5 ± 8.9</td>
<td>0.02</td>
<td>.65</td>
</tr>
<tr>
<td>Step frequency (Hz)</td>
<td>2.94 ± 0.2</td>
<td>2.56 ± 0.2</td>
<td>0.02</td>
<td>.69</td>
</tr>
</tbody>
</table>

**Discussion**

A distinctive kinematic biomechanical profile for the Pose Group was identified. The Pose Group’s biomechanical profile is discussed first, and then both technique groups are evaluated in reference to the biomechanical factors that have been identified with improved running performance.

The Pose Group has been characterised by landing in a pose position (figure 1) where the shoulder, hip and ankle are vertically aligned just after impact (Fletcher et al., 2008). This pose position was evident in the Pose Group because their vertical alignment measured by the right hip’s (greater trochanter marker) horizontal distance behind the right ankle (lateral malleolus marker) was 7.4 cm at 25 ms after impact. Further, pulling the foot from the ground is a key component of the Pose Group (Fletcher et al., 2008). This study’s Pose Group had higher knee flexion angular velocity from terminal stance until mid-swing. Also, the Pose Group had lower knee extension during stance suggesting they are not forcefully extending their legs but rather powerfully flexing their legs into swing. By having less knee extension during the propulsive phase of stance the Pose Group also had lower vertical oscillation of the centre of mass because these variables are correlated (Wank et al., 1998).

Stance time was also significantly lower in the Pose Group. This possibly reflects the significantly shorter horizontal displacement of the centre of mass during stance. A more aligned body position at impact may reduce the horizontal displacement of the centre of mass with a subsequent reduction in stance time. The Pose Group had shorter stride lengths and smaller
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vertical oscillations of the sacrum than their Heel-toe Group for barefoot running (Arendse et al., 2004). In a further study the Pose Group decreased stride length and reduced vertical oscillation of the centre of mass despite extreme fatigue (Dallam et al., 2005). It appears this technique consistently reduces stride length and vertical oscillation of the centre of mass/sacrum because this study also found reductions in a non-fatigued shod condition in the Pose Group. The decreased step length is also matched by a consistent increase in step frequency in the Pose Group (Arendse et al., 2004; Dallam et al., 2005). Step length may decrease because the method teaches that the swing leg is not to be driven forwards; rather the runner should concentrate on pulling their support foot from the ground enabling the swing foot to potentially drop under the body independently (Romanov and Fetcher, 2007). In reference to the increased step frequency the significantly reduced stance time will contribute to the higher step frequency found in the Pose Group.

Stride length and stride frequency commonly evaluate performance between individual runners and their differences at various running speeds (Cavangh and Williams, 1982; Martin, 1985; Patla, 1989). In this study, both technique groups are distinguished by stride length and stride frequency with the Pose Group having consistently shorter step lengths than the Heel-toe Group, but an increased step frequency. The Heel-toe Group’s step frequency in this study’s test speed of 3.35 m/s is similar to other gait studies (for example, Wank et al., 1998). It has been identified within the general running population that 20% of runners overstride (Cavanagh and Williams, 1987; Williams et al., 1991; Morgan et al., 1994). By reducing stride length these runners improved performance (Morgan et al., 1994). The Pose technique does not focus on reducing stride length but instead teaches runners to focus on pulling the support foot from the ground, hence, the swing leg is not driven forwards at terminal stance into swing potentially increasing stride length. Therefore, some runners in the general running population may benefit from Pose running simply via reductions in stride length.

Increased stride length may also contribute to the increase distance of the support foot to the centre of mass at impact because the swing leg is driven forwards from terminal stance into swing. Vertical alignment of the shoulder, hip and ankle in the Pose Group at impact, is more aligned than the Heel-toe Group (7.4 cm compared to 14.1 cm). Interestingly, runners who are more proficient keep their feet as close as possible beneath their centre of mass (Deshon and Nelson, 1964). In support, all sprint finalists (100 m, 200 m and 400 m) from the 1984 Olympics, found Gold medallist’s centre of masses were 0.217 m behind the foot at impact compared to Silver medallists at 0.284 m and eighth position with 0.327 m (Mann and Herman, 1985). It has been well documented that if the foot lands further ahead of the centre of mass at impact for one runner compared to others, a greater braking effect can occur (Fenn, 1930; Deshon and Nelson, 1964; Cavanagh et al., 1977; Bates et al., 1979; Kunz and Kaufman, 1981; Girardin and Roy, 1984). The Pose Group also had their centre of masses 0.249 m behind the foot at impact compared to the Heel-toe Group at 0.327 m. It appears the Pose Group had a vertically aligned body at impact by not reaching forwards with the swing foot. Further, the more extended the knee at impact and the further the foot is in front of the centre of mass, the longer the foot remains on the ground (Kunz and Kaufman, 1981; Mann and Herman, 1985). In support, stance time was significantly less in the Pose Group. There is some support for shorter contact time increasing muscle stiffness and the utilisation of muscle elasticity during the stretch- shortening cycle (Paavolainen et al., 1999).

The success of Kenyan distance runners is self-evident over the last thirty years at international athletic and cross-country championships. Interestingly, Kong and de Heer (2008) identified stance time was 0.21 ms and their stride frequency was 2.92 Hz at similar test speed to this study for six elite Kenyan runners from the Nandi, the sub-tribe of the Kalenjin tribe from which almost all elite Kenyan runners derive. These six elite Kenyan runners had the same stance time and stride frequency as the Pose Group in this study. However, it should be noted other factors might contribute to Kenyan success in running other than technique.

Elite 1500 m runners were compared with national standard 1500 m runners (3 min 35.6 s ± 2.6 s: 3 min 49.2 s ±3.2) to determine kinematic differences (Leskinen et al., 2009). Knee
extension velocity from mid-stance to terminal stance was lower in their elite group than national standard runners (5.6 ± 0.5 vs. 8.3 ± 1.6 rad/s). This study also found the Pose Group (3.92 ± 1.4 rad/s) had lower knee angular extension velocity during stance compared to the Heel-toe Group (4.38 ± 0.3 rad/s). However, stance time did not differ between their 1500 m runners.

Increasing running speed via knee extension lacks support (Mann et al., 1986; Novacheck, 1996; Belli et al., 2002). At terminal stance, the knee does not fully extend although there appears to be a trend towards greater extension with increased speed (Cavanagh et al., 1977; Bates et al., 1979; Elliott and Blanksby, 1979). This finding though is not universal (Sinning and Forsythe, 1970). Knee extension during the propulsive phase of stance may distinguish the Pose Group from the Heel-toe Group. Pose runners are told to pull the foot from the ground soon after mid-stance potentially reducing knee extension and consequently decreasing vertical oscillation of the centre of mass (Wank et al., 1998). Further distinction of the pulling action is seen in the increased knee flexion angular velocity from terminal stance until mid-swing in the Pose Group. Leskinen et al. (2009) also found in the swing phase, peak flexion velocity of the knee joint was greater in their elite runners (14.6 ± 0.8 vs. 13.0 ± 1.2 rad/s) than their national standard runners.

Conclusion

In conclusion, the Pose Group can be characterised by a vertically aligned body at impact that appears to reduce stance time and horizontal displacement of the centre of mass during stance. The Pose Group extends their legs less forcefully during stance but powerfully flexes their legs during swing. This studies findings identified the Pose Group with certain biomechanical factors that have been identified with improved running performance These findings should enable coaches to identify a kinematic profile and key biomechanical performance factors for both techniques. Further work should identify injury incidence and performance differences between the two techniques.

References


