TO EXAMINE THE DIFFERENCES IN REARFOOT KINEMATICS DURING TREADMILL AND OVERGROUND RUNNING

O. Donoghue and A.J. Harrison
Department of Physical Education and Sports Science, University of Limerick, Limerick, Ireland

This study examined the differences between the kinematics of rearfoot motion in overground (OG) and treadmill (TM) running. Two subjects ran at various speeds under both conditions and a three-dimensional analysis was performed using the Peak Motus Analysis system. TM running produced repeatable and consistent measures of rearfoot motion across all speeds however OG running was more variable. While there are some differences between the two modes, this can be explained by TM mechanics and TM testing cannot be dismissed based on this. Speed was found to influence most variables making speed control critical in obtaining reliable measures of rearfoot motion. The TM easily and accurately provides this, which advocates its use in locomotion studies. It was concluded that speed control is more important than the mode of running.

KEY WORDS: treadmill, overground, running, rearfoot, kinematics.

INTRODUCTION: Treadmills are commonly used in biomechanical research as they conveniently control speed, distance, space and environmental factors and allow repetitive strides to be examined (White et al., 1998). There is much debate about the validity of using treadmills for locomotion research. Physiological and biomechanical studies have found conflicting results about differences between these modes of running (Nigg et al, 1995; Anderson). While there are relatively few studies focussing specifically on the three dimensional rearfoot kinematics during OG versus TM running, the results of these are inconsistent and individually specific (Nigg et al, 1995). Speed, mode, footwear and individual movement patterns are known to affect the kinematics of rearfoot motion (Andrew, 1986 cited in Edington et al., 1990). Overground testing is intuitively more appropriate because it does not require change in the normal pattern of movement but it makes data capture more time-consuming. If significant differences exist between TM and OG running kinematics then TM based studies must be viewed with caution. There is a need to evaluate the relative merits of the TM in controlling speed and allowing easy capture of several footfalls against the excessive workload involved in OG running measurement. This study aims to examine the differences in lower limb angular kinematics between OG and TM running and to determine if speed control is more important than mode of running.

METHODS: One female and one male subject (aged: 21, 20 years; mass: 53kg, 64kg; height: 1.65m, 1.77m respectively) provided written, informed consent to participate in the study. Both were 400m athletes with good fitness levels and no injuries at the time of testing. Subjects wore dark coloured Lycra running tights for TM testing and a white T-shirt for the OG running to improve laser reflections. Retroflective markers were placed on the lower extremity of each subject as follows: two on the posterior aspect of the shoe bisecting the heel, two bisecting the posterior shank (one on the Achilles Tendon, one below the belly of the gastrocnemius), one on each of the 5th metatarsal, lateral malleolus and fibular head (see Figure 1). Subjects ran in their own running shoes under two conditions - OG and on a Powerjog GXC200 TM. A laser (LAVEG Sport, Jenoptik, Jena, Germany) was used to measure running speed within the measurement zone in the OG

Figure 1: *Marker setup*

condition. The experimental setup was similar for both conditions. A Peak Motus 17-point calibration frame was set up in the measurement zone. Three genlocked Panasonic DPH800 SVHS cameras operating at 50 Hz (shutter duration 0.002s) were placed to capture the left limb kinematics of the subjects. For the OG condition, the laser was located behind the athlete's starting position 31.5 m from the measurement zone (see Figure 2).

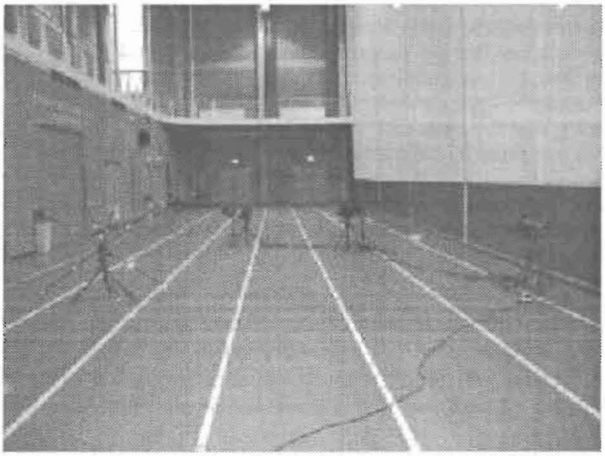


Figure 2: *Experimental setup for overground condition*

TM testing took place first with both subjects Undergoing a familiarisation session prior to data capture. Subjects were videotaped in relaxed standing position in the calibrated space. Subject 1 ran at velocities from 2.22 m.s-1 to 3.89 m.s-1 increasing in 0.28 m.s-1 increments. Subject 2 completed speeds from 2.5 m.s-1 to 3.61 m.s-1. Data capture took place after 2-3 minutes of continuous running. For OG testing, subjects were required to place their left foot in the clearly designated 1 m zone to ensure capture by all three cameras. Fifteen valid trials of varying speed from 3 m.s-1 to 7.22 m.s-1 were obtained. Subjects were given full recovery between trials. The three-dimensional rearfoot variables of frontal and sagittal plane motion were measured and examined using the Peak Motus 6.0 Analysis System (Peak Performance Technologies, Englewood, CO, USA). Table 1 shows the relevant angles that were defined (Stacoff et al., 2000; Nigg et al., 1995). All angles were calculated relative to relaxed standing position and describe the relative changes during stance.

Table 1 : *relevant angles of sagittal and frontal plane rearfoot motion.*

Angle	Definition
Medial lower leg (MLL) angle (α)	Angle between the lower leg and the ground on the medial side from posterior
Rearfoot (Rft) angle (γ)	Angle between the rearfoot and the ground on the medial side from posterior
Achilles Tendon (AT) angle (β)	In/eversion position of rearfoot relative to the lower leg.
Calcaneal DF angle	Angle between the segments of lower leg and foot
Ankle DF angle	Anatomical joint angle between fibular head, ankle and 5^{th} metatarsal
Posterior lower leg (PLL) angle (η)	Angle between the lower leg and the ground on the posterior from lateral view

The angle-time curves were plotted in Microsoft Excel. Angles at heelstrike (HS), maximum deflection from this point during stance and range of motion (ROM) during stance (HS - Maximum deflection) were obtained for each of the angles defined in Table 1. Pearson's Correlations were calculated to determine if speed was correlated to HS, maximum/minimum or ROM values.

RESULTS: Despite the wide range of speeds, the average angle-time curves based on five footfalls at each TM speed were consistent for both subjects with most variation found in medial and posterior lower leg angles. The means and standard deviations (SD) were calculated for HS, maximum and ROM values for six angles at each speed. The SD's across all TM measures exceeded 4 on 2 occasions but were less than 2 for 71.5% of the cases, which confirms the repeatability of this data. This contrasts with the high trial-to-trial variability seen in the OG trials (see Figure 3). These angle time data are considerably less consistent, demonstrating the strong effect of speed variation on rearfoot kinematics during the stance

Figure 3: *Average TM and individual OG angle-time curves for Subject 1*

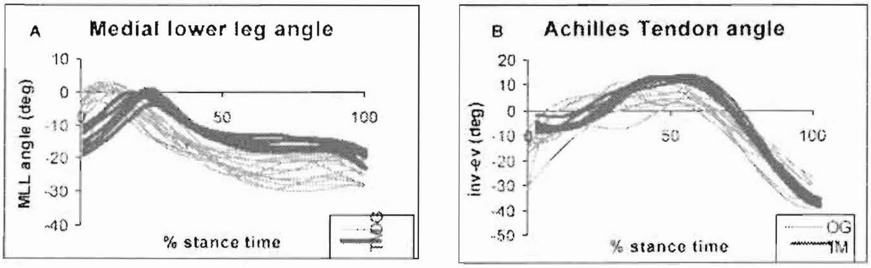
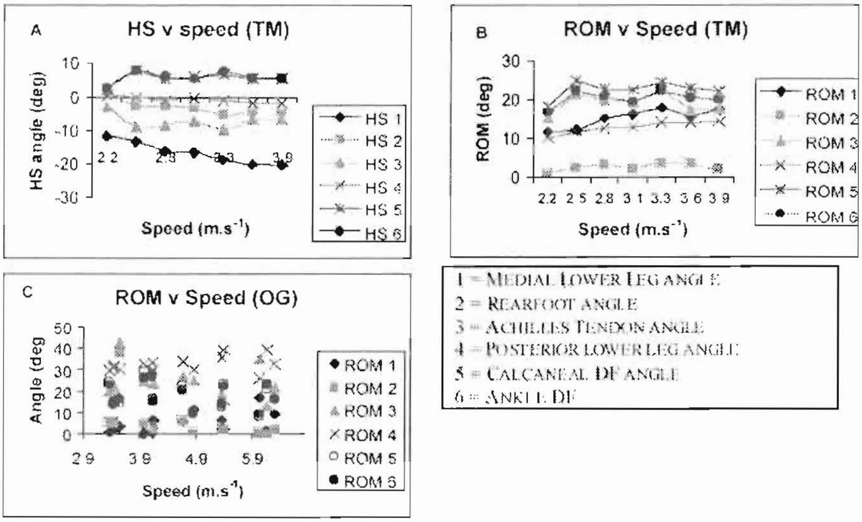


Figure 4: *Estimated marginal means for TM HS and ROM and OG ROM - Subject 1*



phase of running. Figure 4 describes the effects of increasing speed on HS and ROM values for each angle obtained on the TM. Maximum values were generally not affected by running speed but the data revealed trends towards increased EV and DF at HS, maximum EV and downward displacement of the medial and posterior lower leg angle time curves as speed increased. Pearson's Correlations (r) revealed that for Subject 1 on the TM, speed was strongly correlated to medial lower leg HS angle ($r=-0.917$, $p<0.001$) and ROM ($r=0.710$, $p<0.001$), posterior lower leg HS angle ($r=-0.720$, $p<0.001$) and ROM ($r=0.847$, $p<0.001$). For the medial lower leg angle in OG running, speed was correlated to HS angle ($r=-0.719$, $p=0.004$) for Subject 1 and maximum angle ($r=-0.786$, $p<0.001$) and ROM ($r=-0.714$, $p=0.004$) for Subject 2. ROM and HS angles were strongly correlated for all angles and conditions for both subjects.

DISCUSSION: The data in this study show that speed variations alter the angle-time curves and the rearfoot kinematics especially in the OG condition. The same basic kinematic pattern of movement is evident in both TM and OG conditions (Figure 3). While clear A B differences between the two surfaces have been found in temporal and physiological variables these are not relevant in this study. Some differences such as greater lower leg varus angles and less inversion at HS were found but these can be partly explained by difficulties in defining HS events. This could only be rectified by using a higher video frequency in sampling. This also prevented calculations such as time spent in pronation and time to maximum pronation. The mechanics of TM running also account for these differences between modes and can explain why PF and posterior lower leg angle are reduced at HS. These are known and expected deviations from OG running. Other proposed explanations include the different movement of the centre of mass on the TM (Anderson), TM familiarity, altered perceptual and kinaesthetic information, air resistance, differences in mechanical properties of the running surfaces and the constancy of the belt speed (Schache et al., 2001).
While TM speed tends to have a systematic effect on rearfoot movement, OG trials indicate that speed is often not correlated to any of the variables measured. Hence, speed in OG running has random and/or individually specific effects. While OG trials obtained at similar speeds did show improved consistency, they were not as consistent as TM trials at the same speed. This indicates that it is necessary to control speed in kinematic studies of lower limb function in running. TM testing allows this to be done easily and accurately, resulting in low trial-to-trial variation. To obtain the same level of repeatability, OG running is timeconsuming and requires a significantly greater workload to ensure accurate foot placement, no alterations to running pattern and constant speed across repeated trials. The results have already indicated that TM and OG running do not produce identical angletime curves. The subjects perceived a given speed on the TM to be significantly faster and more stressful than a comparable speed completed on the track. This questions the validity of directly comparing a given speed undertaken in both conditions. However, despite this discrepancy, it is not enough to invalidate the use of a TM. Speed control is crucial to ensure low trial-to-trial variation and improve the strength of the study.

CONCLUSION: The TM clearly provides a valid and reliable method of obtaining rearfoot kinematic variables during running. The general pattern of lower limb angular kinematics is similar in OG and TM running. The importance of controlling speed has been identified as a critical factor in ensuring low trial-to trial variability thus lending significant support to the use of treadmills in locomotion studies.

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