CURVED RUNNING IN SOCCER: KINEMATIC DIFFERENCES BETWEEN THE INSIDE AND OUTSIDE LIMBS

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Research on curved running has focussed on track running, using radii not applicable to common movements in many sports. The nature and function of the inside and outside limbs movement remains undocumented in the literature. Common radii of curved runs and typical movement speeds were noted from English Premier League soccer. Eight male soccer players ran at three speeds (3.5 m/s, 4.5 m/s, 5.4 m/s) during straight (0m), and along a curve of radius 3.5m on natural turf. Three dimensional kinematic data was collected using Peak Motus software at 50 Hz. During curved running results indicated reduced range of motion at the outside and inside ankle and knee, but greater hip joint range evident at the inside compared to the outside leg, with emphasis at higher speed. Greater hip flexion positions the centre of mass to allow body lean to complete the curve.

KEY WORDS: curve, kinematics, leg, running, soccer.

INTRODUCTION:

There have been kinematic investigations into curvilinear motion in athletics, due to the curved nature of the bend sections on the track. Research has primarily focused on maximal sprinting and the assumption that constant stride length (SL) and stride frequency (SF) were maintained (Greene and McMahon, 1979; Stoner and Ben-Siri, 1979; Greene, 1985 and Hamill *et al*., 1987). More recent work by Smith *et al*. (1997) showed that constant SL and SF did not apply to constant sub-maximal paced curved motion at two discrete speeds of 5.4m/s (running) and 4.5m/s (jogging) over three radii of curves (5m, 7.5m and 10m). Smith *et al*. (1997) observed greater lower extremity adaptations during smaller radii (5m), primarily a reduced stride length in the outside leg whilst running, and so therefore verified the claims of Stoner and Ben-Siri (1979) who suggested different movement patterns between inside and outside limbs during curvilinear motion. Due to the constantly changing orientation of the sagittal plane during curvilinear motion, three-dimensional kinematics is essential to assess and evaluate whole body adaptations during curvilinear motion.

The ability of the player to perform and maintain motion through a curved path may be considered an essential component of soccer play. Notational analysis work based on the analysis of soccer play by the current authors, revealed the curvilinear movement pattern to range from 3.5m to 11m radii at a variety of velocities (Brice *et al*., 2004). A typical soccer game related scenario involved a curved run along the defensive line in order to remain onside. A greater understanding of the execution of curved motion may identify biomechanical components of the skill underlying its performance.

In this study of curved motion, a non-planar activity, 3D kinematic measurement was used as this would best identify key adaptations that occur. For ecological validity to soccer, all trials were performed on natural turf surface, wearing standardised soccer footwear. The aim of the present investigation was to identify the key segmental adaptations occurring at the inside and outside legs during curved motion by comparison with a straight path.

METHOD:

Eight male soccer players (age 21.7 ± 2.3 years; mass 72.3 ± 6.4 Kg) volunteered for the study. All subjects were of similar ability (University 1st XI) and reported no injuries or health issues of concern prior to testing. All subjects wore appropriate soccer apparel. Informed consent was obtained and subjects were free to withdraw from study without prejudice at any time. The study had received University ethical clearance.

An earlier notational analysis study, observing 24 Premier league players, revealed the presence of curvilinear motion to range from 3.5m to 11m radius of a curve during current soccer play (Brice *et al*., 2004). Upon arrival at the testing venue all subjects were given sufficient time to warm up and familiarise themselves with the linear (0m), curved paths (3.5m), and criterion velocities (5.4m/s, 4.5m/s and 3.5m/s). The velocities represented 3.5m/s (recovery run), 4.5m/s (jogging) and 5.4m/s (running) in soccer. All subjects performed 12 individual trials wearing standardised soccer footwear (Pro-model Mizuno, size 8 or 9) on natural turf.

Motion was monitored by 2 sets of infrared timing light gates (Cla-Win timer, UoC, UK) situated 2m apart at greater trochanter height, within the calibrated movement space. Subject motion was monitored during each trial by two video cameras (Panasonic VHS), which sampled at 50 Hz, genlocked with the optical axis positioned approximately 120 degrees apart, with a shutter speed of 1/500. Subjects were required to produce the correct criterion velocity (± 5%), with a trial only successful if a full stride cycle of right heel strike (RHS1) to right heel strike (RHS2) was performed within the calibration space. Prior to each trial a 25 point three dimensional calibration frame was placed in the movement space and aligned with its axis along the tangent of the curve. (Peak Performance Technologies, Englewood, USA).

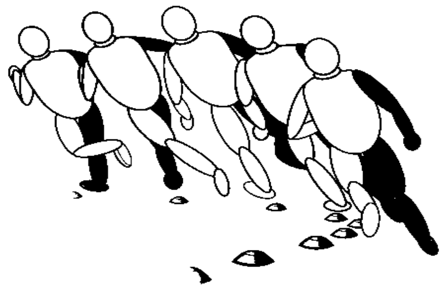

Figure 1: Five key sequential events (RHS`1, RTO, LHS, LTO, RHS2) during one complete stride cycle of curvilinear motion. Note: White indicates inside left limb and black indicates outside right limb.

Image digitisation and analysis were performed by Motus 32 software (Peak Performance technology, Englewood, USA). All trials were digitised at 50 Hz using a 16 point whole body model, with each view digitised sequentially. Five key events of right heel strike (RHS1), right toe off (RTO), left heel strike (LHS), left toe off (LTO) and right heel strike (RHS2) signified one complete stride cycle. Values of hip angles in this research were calculated from the anatomical landmarks of the knee, hip and shoulder. The data were filtered using a Butterworth low pass filter, with a cut off frequency of 5 Hz. The effect of the Butterworth cut off frequency upon the data was observed at 3, 4, 5, 6 and 7 Hz. For the anatomical angles the 5 Hz cut off maintained the essence of the movement, whilst minimising systematic error from the raw data compared to other cut off frequencies.

To assess differences in lower extremity movement at each joint (inside ankle, outside ankle, inside knee, outside knee, inside hip, outside hip, inside shoulder and outside shoulder angles) during the stride cycle, minimal, maximal and range data were compared statistically adopting a 2 way ANOVA with repeated measures (curve x speed). Differences were reported at the $P < 0.05$ significance level.

RESULTS:

There was a notable difference in the timing of key events during the stride cycle when running along the 3.5 m curved path compared to the straight path as shown in Figure 2. The length of the stride cycle became shorter in time when running along a curved path.

Table 1 indicated the significantly greater range of motion (ROM) occurring during straight running at the inside and outside ankles and inside and outside knees, compared to curved running. In contrast, the outside and inside hip ROM data indicated greater ROM during curved running compared to the straight running. Table 2 indicated the predominant increase in the inside hip ROM at the higher running speed as the hip flexed 62 degrees from the minimal 12 degrees extension position. This highlighted the relative importance of hip flexion of the inside leg, during the tightest curvatures, enabling the body to lean into the curve and offset the toppling moment towards the outside of the curve. In comparison at the slower recovery run speed the inside hip flexion was only 49 degrees.

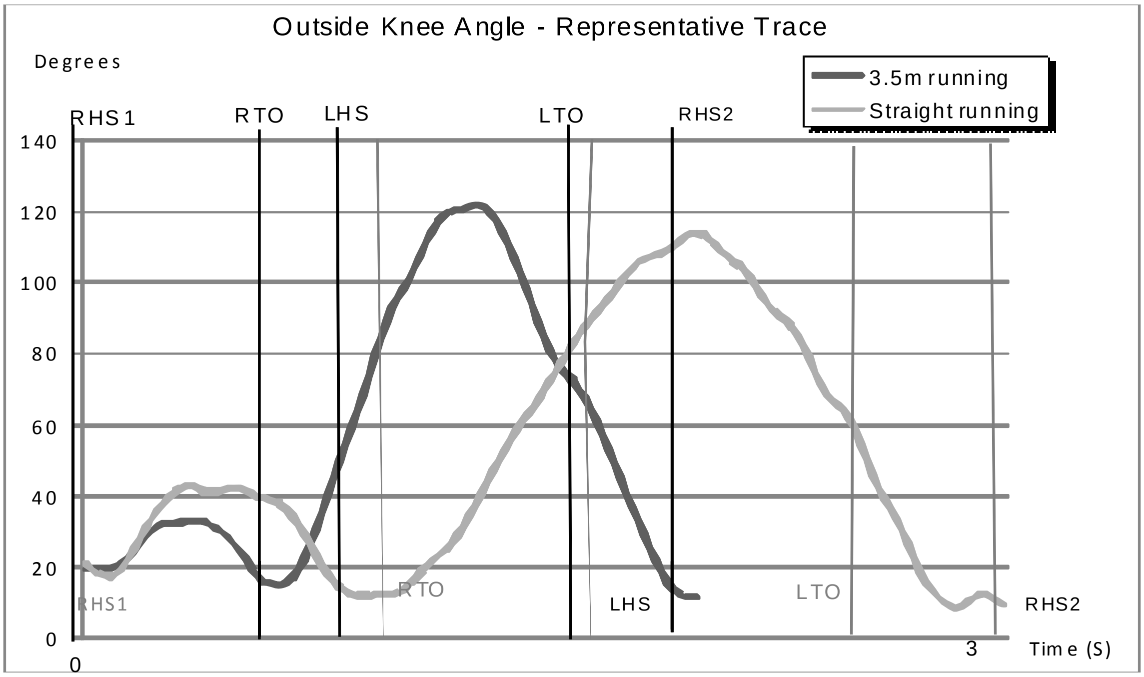

Figure 2: Curved running involves a reduction in the length of the stride cycle during the swing-phase. Representative data of the outside knee joint angle showing comparison of data for straight running and running along a 3.5m curved path shown relative to key events of the stride cycle.

Table 1. Mean range of motion (ROM) maximum and minimum values for straight (0m) and curved (3.5m) radii running at 5.4m/s indicating the increased ROM in curved running at both the inside and outside hip (Significant differences p<0.05 denoted by *).

Joint	Straight			Curved		
	ROM(°)	Max (°)	Min(°)	ROM(°)	Max(°)	Min(°)
Outside Ankle	**54.1**	104.5	50.4	**48.9***	99.1	50.2
Inside Ankle	**60.0**	105.8	45.8	**56.7***	105.0	48.3
Outside Knee	**103.9**	108.3	4.4	**99.2***	114.1	14.9
Inside Knee	**110.5**	118.7	8.1	**109.3***	124.9	15.5
Outside Hip	**39.2**	42.8	3.6	**48.3***	57.6	9.3
Inside Hip	**52.3**	57.1	4.8	**62.6***	74.9	12.3
Outside Shoulder	**32.2**	153.0	120.7	**41.1**	159.6	118.6
Inside Shoulder	**36.1**	160.7	124.7	**34.2**	160.6	126.4

Tables 1 and 2 indicated the greater ROM at the hip during running along a curved path and therefore identified the likely greater energetic requirements of accomplishing curved motion, particularly at higher speeds. Increased angles of flexion at the hip will reduce moments of inertia about the lower extremity. Therefore, the closer the centre of masses of the leg segments become with increased joint flexion, the less muscular energy is required to achieve rotation of the lower extremity.

Table 2. Mean range of motion (ROM) values during 3.5m curved motion for the hip of the outside and inside legs during running, jogging and the slower recovery run speed

Speed	Outside leg			Inside leg		
	ROM(°)	Max(°)	Min(°)	ROM(°)	Max(°)	Min(°)
Running	**48.3**	57.6	9.3	**62.6**	74.9	12.3
Jogging	**41.8**	47.3	5.5	**56.6**	63.8	7.1
Recovery	**35.2**	39.5	4.2	**49.3**	55.1	5.8

Smith *et al*. (1997) displayed reduced stride length and increased stride frequency during curved running. This current investigation would support claims of reduced stride length being reflected in lower ranges of motion of the knee and ankle during curved running (Figure 2 and Table 1). Previous research by Stoner and Ben-Siri (1979), and Hamill *et al*. (1987) did not use footwear or surfaces relevant to soccer performance, and did not monitor a range of speeds as in the current study.

Overall range of motion at the hip determined in this research of 39.2° for the outside hip in straight running at 5.4 m/s agreed with Cavanagh's (1990) reports of mean values of 38°, thus supporting the running style measured in this investigation was typical of the wider population. In curved running hip joint asymmetry, with greater flexion at the inside hip, will enable lateral pelvic tilt which should facilitate lean of the torso, and positioning of the body centre of gravity inside the base of support. This would oppose the toppling moment towards the outside of the curve.

CONCLUSION:

Comparison of running kinematics along a straight and curved path has revealed the adaptations necessary to progress along a curved path on grass turf in studded soccer boots. Key mechanisms were apparent in the performance of curved running, notably a greater amount of hip flexion particularly of the inside leg where increased flexion of the knee and ankle were also evident. Such an increased hip flexion may involve the centre of mass altering its orientation in order to complete the curved motion. Coaches and trainers may wish to highlight the importance of shorter stride time and achievement of a lower centre of mass by increased hip flexion, particularly at the inside hip when coaching or correcting running techniques in soccer specific movements.

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