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Technical adaptations of competitive sprinters induced by bend running

By Gary J. Ryan, Andrew J. Harrison

ABSTRACT

The effect of lane draw is believed to be a significant factor in determining sprint performance, especially in indoor 200m and 400m races. Anecdotal and mathematical evidence suggests that there is a disadvantage in running in lanes of lesser radius in the 200m. The purpose of this study was to examine the effect of bend radius on sprint performance and on deterministic parameters of sprinting namely, stride length (defined as the length of a single step), stride frequency, ground contact time and lower limb kinematics. Thirteen competitive sprinters were video-taped while running at maximum speed in lanes 1 and 4 of an indoor track and lanes 1 and 8 and of an outdoor track. A 10m segment of the sprint was captured on a panning video camera located at the centre of the curve. The video data was digitised using Peak Motus ®, corrected for the effects of pan and tilt of the camera and the kinematic data were determined.

Results showed significant differences in contact time, stride length, stride frequency and range of motion of the left knee due to differences in bend radius. It is suggested that the change in contact time is due to an accommodation by the athlete for the effects of centripetal force, thus also affecting the stride length and rate.

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Introduction

In sprinting events such as 200m and 400m, the athlete has to cope with running a curved path at maximum or near-maximum speed. It is generally accepted as a consequence of running a bend, that performance times will be worse when compared to straight sprinting. The detrimental effect of the bend on performance appears to increase as the bend radius decreases, however there is little experimental evidence to support this assertion.

Anecdotal evidence and the performance times at major championships supports the view that the inner lanes of a 200m race are 'slower' than the outer lanes. Table 1 shows average performance 200m times during rounds 2, 3, and 4 in lanes 1, 2, 7 and 8 for the Olympic Games in 1996 and 2000 and the 2001 IAAF World Championships in Athletics. Correct interpretation of these data however, requires consideration of IAAF seeding procedures. These specify that in all but the first round in outdoor races, lanes 3, 4, 5 and 6 should be reserved for the higher seeded athletes. The data in Table 1 shows that in the two inner lanes, performance times are generally worse than the two outer lanes despite the fact that seeding procedures tend to match athletes in these lanes based on their performances from previous rounds. It is also noteworthy that in the 1996 Olympic Games 200m event, lane 1 was the only lane where a national record was not achieved, only one athlete qualified for a later round from lane 1 and any athlete who qualified from an outer lane ran slower if placed in an inner lane in a subsequent round. In indoor competitions, performance times in 200m races are generally much slower than outdoor races. The IAAF have recognised the effect of lane draw on performance in indoor competitions and the outside three lanes are generally reserved for the higher seeds. Additionally, in the 2001 IAAF World Indoor Championships 200m event, lane 1 was only used in the final.

Although the technical aspects of sprinting have been quite thoroughly researched, relatively few studies have examined the biomechanics of bend running. Published work in bend running research can be broadly classified into three main areas:

1. Theoretical studies where the athlete is treated as a point mass moving at constant speed around a circular path.
2. Investigations based on the statistics of competition results and 100m split times in 200m races.
3. Experimental studies examining the effects of the bend radius on the biomechanics of performance.

Theoretical studies represent the largest proportion of research on the effects of bend running, examples include: Keller (1973), Alexandrov and Lucht (1981), and Murieka (1997). These have considered the changes in running speed induced by the bend by modelling the body as a single particle mass travelling a circular path at a constant speed and applying Newtonian mechanics laws. Although this approach may explain the gross biomechanics of bend running, the finer details of how the bend radius might affect specific aspects of technique remains unclear. Furthermore, the particle model of the athlete travelling a circular path at constant speed may be convenient but it is logically unsatisfactory since it assumes the athlete is subject to a continuous centripetal force. This is a false assumption, since the athlete can only generate a centripetal ground reaction force component during a ground contact phase. Typically, during sprinting the athlete will only be in contact with the ground for about 40% of the stride time (Mero et al, 1992; Thordarson, 1997) therefore, such theoretical models tend to underestimate the size of the centripetal force component.

The results of statistically based studies examining the effects of the bend on performance have been directed primarily at

Average Times (sec)			
Lane	**Olympics 1996**	**Olympics 2000**	**IAAF World Champships 2001**
1	20.91	20.66	20.64
2	20.66	20.77	20.61
7	20.56	20.62	20.50
8	20.57	20.47	20.58

Table 1: Average performance times for 200m for rounds 2, 3 and 4 in the 1996 and 2000 Olympic Games and the 2001 IAAF World Championships in Athletics.

determining the differences between straight and bend running, e.g. Jain (1980), Morton (1997), Greene (1985), Behncke (1994). Generally, these studies are based on athletes' best performance times on the straight compared with running on the bend. Some statistically based investigations combine statistical data with the point mass mathematical models described previously, e.g. Alexandrov and Lucht (1981). The solutions offered by these statistical investigations have been inconsistent and somewhat speculative. Greene (1985) estimated a difference of 0.37 sec between 100m straight running and running a bend with a radius of 38.5m. Behncke (1994) estimated the difference at 0.324 sec for the same radius. Jain (1980) estimated the difference at 0.4 sec without specifying the bend radius. Alexandrov & Lucht (1981) estimated the difference between the bend (r = 40.37m) and straight at just 0.177 sec, a considerably lower estimation for a larger radius. Whilst all authors used similar (i.e. particle mass) modelling techniques the differences in the predictions arise out of differences in the statistical data used by each. This is an inherent problem in statistically based modelling when compared to controlled experimental studies.

Relatively few experimental studies have been conducted on the effect of bend radius on sprinting speed and technique. Notable exceptions include, Greene (1985) and Greene (1987) who found that bend radius affected running speed with the smaller radii causing lower running speed on both banked and flat tracks. However, the way that the bend affects running technique with respect to deterministic factors such as stride frequency and stride length remains unclear. The adjustments made by sprinters to accommodate the bend have received relatively little attention, but from a technique perspective, it is the understanding of these adjustments that is, perhaps, most important to the athlete and coach. The technical factors that determine successful sprinting speed and their interrelationship with each other are well established and described in Hay's (1995) deterministic model of running. Experimental research, for example Luhtanen and Komi (1978), Mehrikadze and Tabatschnik (1983), and more recently, Donati (1995) have determined stride length and stride frequency in sprinting on the straight and how these factors interact with increasing speed.

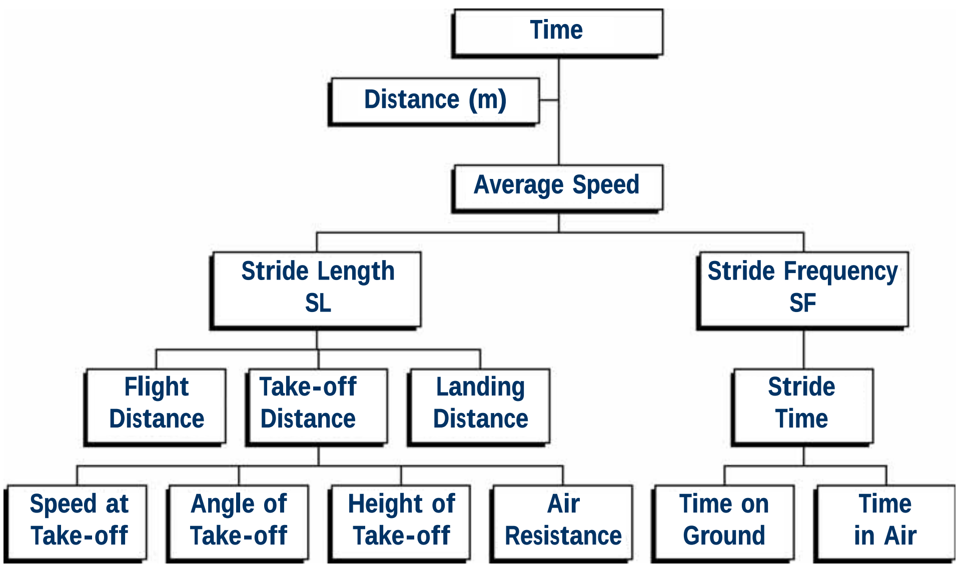

Figure 1: Deterministic model for sprinting adapted from Hay (1995)

The aim of this study was to examine the effect of bend radius on lower limb kinematics and on the factors that directly determine sprint speed: stride length (SL, defined as the length of a single step), stride rate or frequency (SR) and ground contact time (CT). These variables were selected based on the deterministic model of running, Hay (1995).

Methods

Subjects

Thirteen competitive sprinters, 8 men and 5 women, took part in this investigation. Subjects' outdoor personal best times for the 200m ranged: 20.67 sec to 22.10 sec for men and 24.06 sec to 24.50 sec for women. All subjects completed an informed consent form, were free from injury and considered themselves capable of competing at a level close to their best at the time of testing.

Procedures

Subject preparation: Subjects wore circular retro-reflective tape markers to aid identification of the joint centres during video digitisation. The marker loci, 13 segment spatial model and joint angle definitions are illustrated in Figure 2. For the left leg, markers were placed on the lateral aspect of the limb, for the right leg, markers were placed on the medial aspect. Ten reference markers were also placed on the ground 1m apart in the approximate plane of the athlete's running path. Each subject was required to sprint at maximum effort over a 70m section of track including a curved section of at least 33m. Sprint trials were carried out on four different bend radii by all subjects:

- Indoor lanes 1 and 4
  (r = 10.5m and 13.5m respectively)
- Outdoor lanes 1 and 8
  (r = 36.5m and 45.04m respectively).

The indoor track was made of the same synthetic running surface as the outdoor track but was banked on the curved sections. During each running trial, the subjects were videotaped using a panning Panasonic AG450 SVHS (50 Hz.) camcorder mounted on

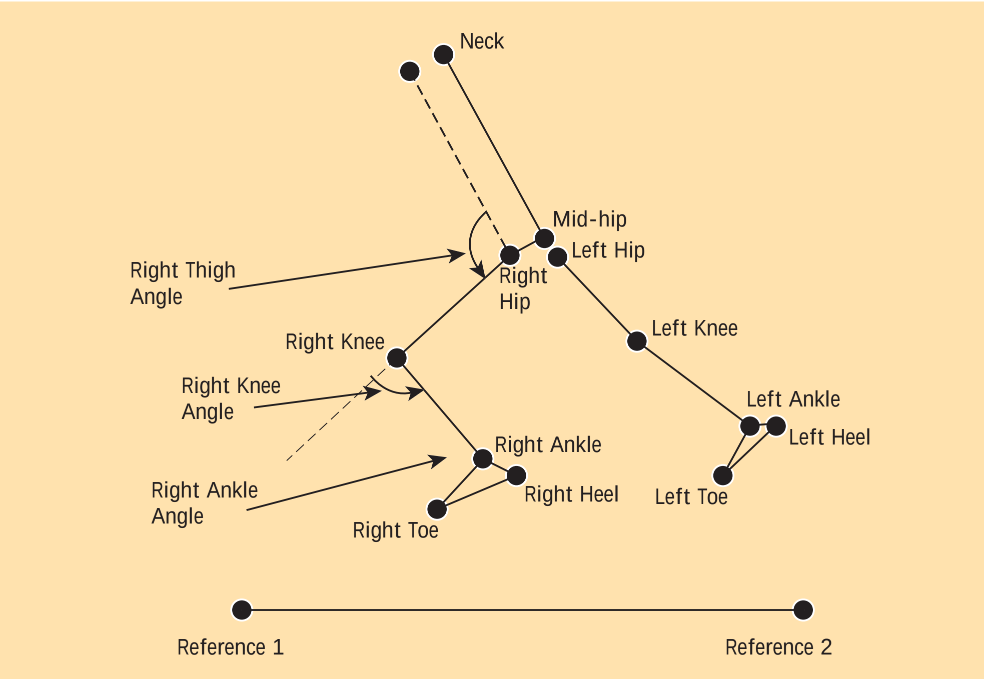

Figure 2: Markers and spatial model used for digitisation.

a tripod and positioned at the centre of the track semi-circle. A 10m section at 50-60m of the 70m sprint trial was selected for analysis. In all cases, this provided a sequence of two complete stride cycles, (i.e. 4 steps) of data.

Data Analysis: All trials were digitised in Peak Motus 3.0® (Peak Performance Technologies, Englewood, CO, USA) at 50Hz. Two static reference markers were digitised in any given field and these were used to scale the raw co-ordinates and to adjust for the panning effects of the camera. The location of the marker for the right hip, which was not visible to the camera during data capture, was estimated by manual digitisation. Raw coordinate data was exported from Peak Motus and correction for pan was carried out in Microsoft Excel using Visual Basic macros. (See Appendix A, for details).

The transformed data was imported back into Peak Motus for data scaling, filtering and analysis. Joint angle-time histories were calculated in Peak Motus for knee, ankle and thigh angles. The knee and ankle joints were defined as angles between two co-joined segments. The thigh angle was defined as the angle between the trunk and thigh segments (see Figure 2). The joint angle-time histories were normalised to percentage of stride cycle using a cubic spline re-interpolation technique in Matlab (The MathWorks, Inc., MA, USA). The maximum ranges of motion of the joints, i.e. joint amplitudes were obtained from the respective joint angle-time histories. Calculation of SL, SR, CT and running speed was obtained from the transformed scaled coordinate data. Stride length was defined as the distance between the toe markers at the first contact of each foot placement. Stride frequency (SR) was defined as mathematical inverse of stride duration and stride duration was defined as the time between consecutive foot impacts of the opposite feet. Contact time was defined as the time from first foot impact until toe-off during each foot contact and was obtained by counting video fields. Running speed was defined as the product of stride frequency and stride length.

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Statistical Analysis: All data was exported to SPSS for hypotheses testing. A GLM repeated measures ANOVA design was used to determine if significant bend related effects existed in the dependent variables SR, SL, CT and running speed. A second GLM repeated measures ANOVA was used to test for significant bend related effects on the ranges of motion of the ankle, knee and thigh angles. The experiment-wise type I error level was maintained at p £ 0.05 for all tests. Tukey's LSD post hoc test was used to determine specific pairwise significant differences between lanes.

Results

Figure 3 provides a comparison of the mean knee joint angle-time histories for in lanes 'Indoor 1' and 'Outdoor 8'. For clarity, the standard deviation bars are provided only on the 'Indoor 1' graphs and the mean graphs for 'Indoor 4' and 'Outdoor 1' have been omitted. Figures 3a and b show a general trend towards greater knee flexion during the ground contact periods in the 'Indoor 1' lane compared with 'Outdoor 8'. This trend was greater in the left knee (Figure 3b) compared with the right (Figure 3a).

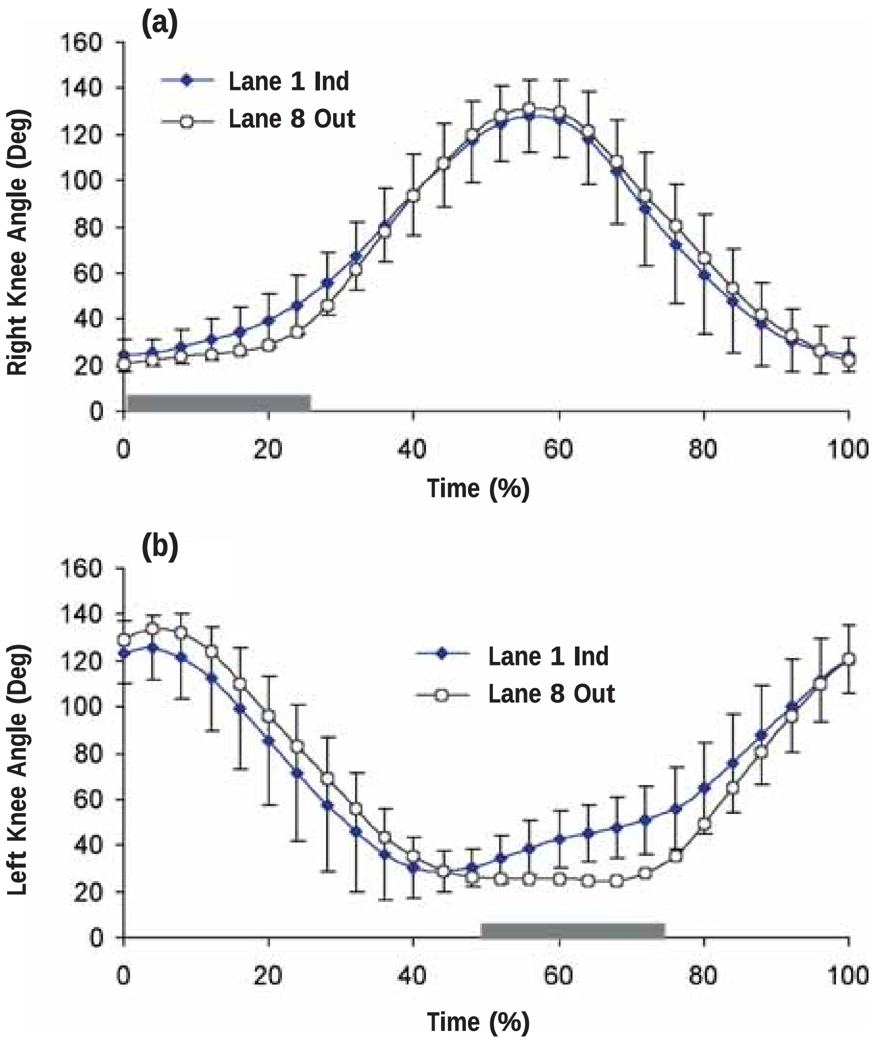

Figure 3 : Graphs of the mean knee joint angle with respect to percentage stride cycle in lanes 'Indoor 1' and 'Outdoor 8'. (a) shows the right knee angle, (b) shows the left knee angle. The grey bars on the horizontal axes indicate approximate foot contact periods.

Figure 4 compares the mean joint amplitudes for the knees, ankles and thighs in lanes 1 and 4 on the indoor track.

The results of the repeated measures ANOVA on the joint amplitude data for the right and left knee, ankle and thigh angles

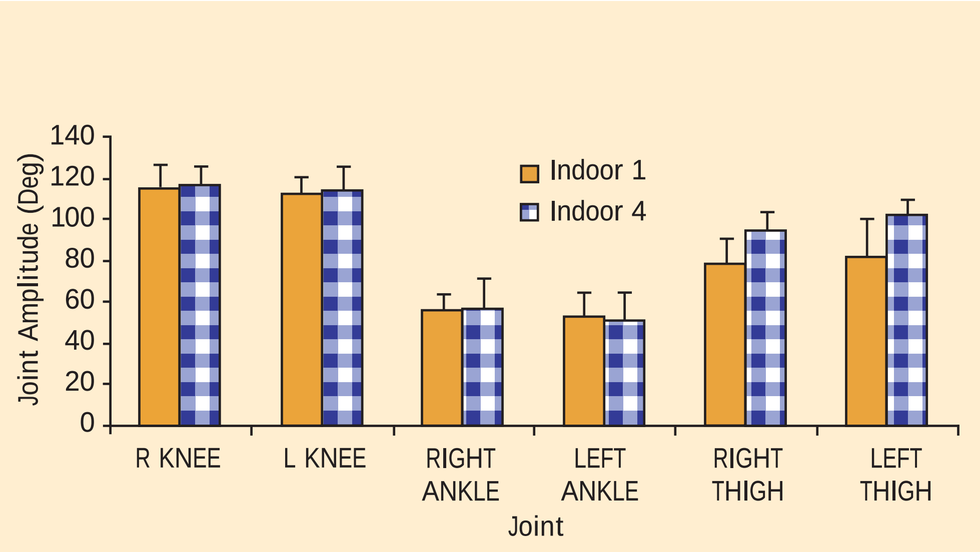

Figure 4 : Comparison of mean joint amplitudes for right and left knee, ankle and thigh angles on each of the inner and outer bends on the indoor track (lanes 1 and 4).

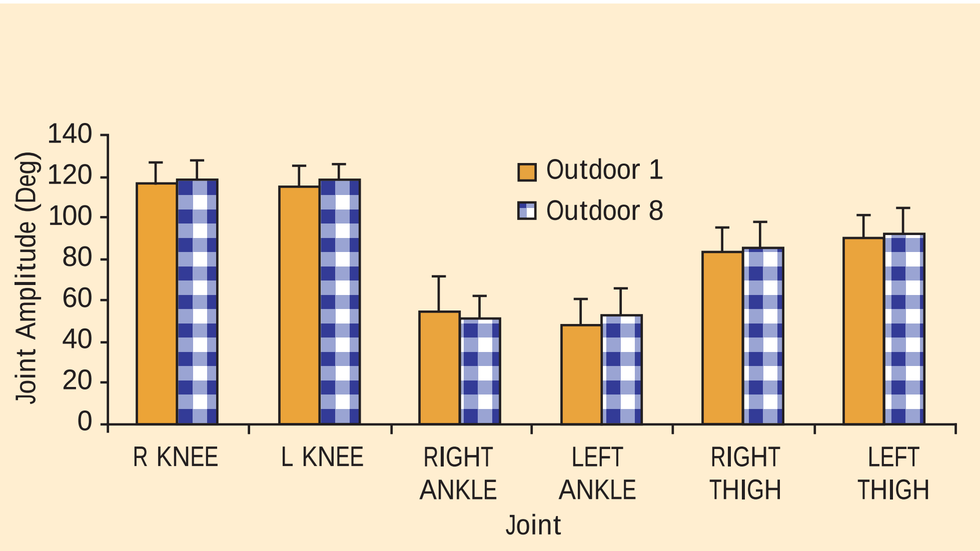

Figure 5 : Comparison of mean joint amplitudes for right and left knee, ankle and thigh angles on each of the inner and outer bends on the outdoor track (lanes 1 and 8).

Figure 5 compares the mean joint amplitudes for the knees, ankles and thighs in lanes 1 and 8 on the outdoor track.

found no significant main effects for bend radius. The effects of bend radius on SL, SR, CT and running speed are shown in Table 2.

Lane	Stride Length (m)	Stride Rate (Hz)	Contact Time (sec)	Speed (m/sec-1)
Indoor 1	1.82 (±0.081)	4.47 (±0.412)	0.113 (±0.015)	8.14 (±0.830)
Indoor 4	1.89 (±0.098)	4.48 (±0.429)	0.104 (±0.016)	8.44 (±0.872)
Outdoor 1	1.99 (±0.118)	4.37 (±0.339)	0.097 (±0.016)	8.70 (±0.775)
Outdoor 8	2.00 (±0.092)	4.51 (±0.445)	0.097 (±0.015)	9.08 (±0.818)

Table 2: Mean ±SD values for SL, SR, CT and running speed with respect to running lane.

Tables 3, 4, 5 and 6 show pair-wise differences caused by the bend radius on SL, SR, CT and speed respectively.

The repeated measures ANOVA showed significant bend-related effects on all variables: SL, SR, CT and running speed, (p£0.05). The specific effects were that running speed and SL increased progressively as radius increased. CT decreased as bend radius increased up to 36.5m (Outdoor 1) and thereafter remained constant. SR generally showed no significant bend related effect except between lanes 1 and 8 outdoors. Post hoc pair-wise comparisons showed significant differences in SL and running speed between all lanes. Post hoc pair-wise comparisons of CT showed significant differences between all pairs of lanes except lanes ‘Outdoor 1’ and ‘Outdoor 8’.

Discussion

The results indicated clear bend related effects on running speed, this is consistent with the results of the previous studies of Greene (1985) and Greene (1987). Inspection of the SL and CT data revealed that SL and running speed increased with increasing radius and CT generally decreased as the radius increased. These data show that running in an inner lane presents the athlete with clear disadvantage, which is most apparent in indoor races where the radius of curvature is smallest. Although the data indicated that athletes have a longer CT in the inner lanes, it is important to recognise that the CT could only be measured to the nearest 0.02 seconds. Further investigation of CT using more precise methods of measurement is recommended. Despite this limitation, the longer CT in the bends of smaller radius is consistent with the reductions in running speed and SL. These reductions can be logically explained by the increased centripetal acceleration that is likely to occur when sprinting at maximum effort on bends of smaller radii. In these inner lanes the athlete will be required to generate greater centripetal force. Since maximum force production is limited by leg strength, the athlete will spend more time in contact with the ground to maximise impulse generation and maintain flight distance. The banking on an indoor track, if optimally designed, may assist the athlete to redirect the ground reaction force so that it will be normal (i.e. perpendicular to the ground). This will help the athlete to generate a centripetal force component but ultimately the athlete will lose speed because the magnitude of the normal force will increase as the bend radius decreases and the athlete will experience a sense of being ‘heavier’ due to the increased ground reaction forces at high running speeds on tight bends. Although the athlete may work at maximum effort, he/she will be unable to maintain the flight distance component of stride length because of difficulties in generating enough impulse and consequently, stride length will decrease.

The results of the analysis of lower limb kinematics (Figures 3a and 3b) show some trends, which are consistent with the changes of running speed, SL and CT in bends of smaller radii. Figure 3 shows that during the ground contact periods there was a trend of greater knee flexion in the ‘Indoor 1’ lane compared to ‘Outdoor 8’. This would be consistent with the explanation that running on the indoor bends

Differences SL (m)	Indoor 1 (m)	Indoor 4 (m)	Outdoor 1 (m)	Outdoor 8 (m)
Indoor 1	0.000	0.067 *	0.163 *	0.178 *
Indoor 4		0.000	0.095 *	0.109 *
Outdoor 1			0.000	0.014 *
Outdoor 8				0.000

* $p<0.05$

Table 3: Pair-wise comparison of Quality Error Differences in stride length (SL).

Differences SR (Hz)	Indoor 1 (Hz)	Indoor 4 (Hz)	Outdoor 1 (Hz)	Outdoor 8
Indoor 1	0.000	0.009	0.095	0.072
Indoor 4		0.000	0.009	0.063
Outdoor 1			0.000	0.167 *
Outdoor 8				0.000

* $p<0.05$

Table 4: Pair-wise comparison of Quality Error Differences in stride frequency (SR)

Differences CT (sec)	Indoor 1 (sec)	Indoor 4 (sec)	Outdoor 1 (sec)	Outdoor 8
Indoor 1	0.000	0.008 *	0.015 **	0.016 **
Indoor 4		0.000	0.007 *	0.007 *
Outdoor 1			0.000	0.000
Outdoor 8				0.000

* $p<0.05$; ** $p<0.01$

Table 5: Pair-wise comparison of Quality Error Differences in ground contact time (CT)

Differences Speed	Indoor 1 (m/sec^{-1})	Indoor 4 (m/sec^{-1})	Outdoor 1 (m/sec^{-1})	Outdoor 8
Indoor 1	0.000	0.311 **	0.585 **	0.910 **
Indoor 4		0.000	0.272 *	0.599 **
Outdoor 1			0.000	0.327 **
Outdoor 8				0.000

* $p<0.05$; ** $p<0.01$

Table 6: Pair-wise comparison of Quality Error Differences in running speed.

increased the ground reaction forces and consequently caused greater flexion in the knee and ankle joints. However, as indicated by the ANOVA on joint amplitude data, this trend was probably not statistically significant.

The kinematic data also shows that the bend related differences in knee joint function were more obvious in the left limb compared with the right and this suggests an asymmetrical effect of bend radius on limb kinematics. It has been suggested by Behncke (1994) that in order to negotiate the bend, athletes may use an asymmetrical stride pattern, i.e. the left to right stride length and duration may be different from the right to left stride length and duration. While figures 3a and 3b do appear to suggest limb asymmetry in knee joint function during ground contact, it is important to recognise the limitations of the analysis techniques used in this study. During data capture the right hip marker was not visible to the camera and although this would not affect measures of SL, SR and CT it could affect measures in knee angles. The 2-D panning technique used in this experiment was therefore not suitable to determine asymmetries in stride pattern that may exist as a result of bend running. It could also be suggested that these asymmetries may be a result of the banking of the indoor track rather than the bend radius and it is therefore difficult to compare results on banked and unbanked tracks. However, it would not have been possible to ask athletes to run at maximum effort on a flat track with such small bend radii without risking injury. Accurate evaluation of such asymmetries would require a 3-D kinematic analysis. This could be a useful avenue for further research.

Conclusions and Implications

The results of this investigation show that the smaller radii of the inner lanes of a 200m race are likely to cause a reduction in maximum running speed resulting from significant changes in contact time and stride length. It is argued that the change in contact time is due to an accommodation by the athlete for the effects of increased centripetal force required to run the tighter bend and this also affects the stride length and rate. The data supports the seeding procedures adopted in indoor competitions where outer lanes are reserved for higher seeded athletes.

Appendix A : Procedures for software correction of camera panning.

The correction for panning involved two transformations (**A** and **B**). The following equations describe these transformations on a sequence of N fields raw x-coordinate data:

$$X^A = PX_T - (R_1X_T - R_1X_1)$$

Where:
- X^A = the x coordinate following transformation **A**
- PX_T = the x coordinate of any point in field **T**
- R_1X_T = the x coordinate of the first reference marker in field **T**
- R_1X_1 = the x coordinate of the first reference marker in field 1

Transformation **A** was applied in a similar way to all the raw y coordinate data. This transformation was valid whilst the reference markers $\mathbf{R_1X_1}$ and $\mathbf{R_2X_2}$ were in the camera field of view. As the camera panned and the athlete passed the initial reference markers, $\mathbf{R_1X_1}$ and $\mathbf{R_2X_2}$ disappeared from the field of view and two new reference markers were substituted. The overall effect of transformation **A** was that the subject's motion resembled treadmill running. Transformation **B** was then applied using the equation:

$$PX^B = PX^A{}_T + (R_1X_1{}^A - R_1X{T_1}^A)$$

Where:
- PX^B = the final x coordinate following transformation **B**
- $PX^A{}_T$ = the x coordinate in field **T** following transformation **A**
- $R_1X_1{}^A$ = the x coordinate of reference 1 in field 1 following transformation **A**
- $R_1XT_1{}^A$ = the x coordinate of reference 1 in field T following transformation **A**

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