ASYMMETRY IN KINEMATIC MEASURES DURING CURVILINEAR RUNNING

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The ability to perform curvilinear motion underpins many non-linear actions in sports. Previous research in the area would suggest that the inside and outside limbs have different actions in such movements. This study aimed to show any asymmetry during the contact phase, measuring rearfoot, forefoot, and total foot contact times. Data was collected using rear and forefoot footswitches at 500 Hz whilst subjects moved through curved arcs of radii 0, 5, 10 and 15m, at two discrete velocities of $4.4ms^{-1}$ and $5.4ms^{-1}$. Total foot contact time remained the same, yet greater stride frequency as the curve became tighter meant proportional foot contact time increased. Stride length decreased at the outside leg but not the inside leg, with greater rearfoot contact at the outside leg at tighter radii showing altered function of the two limbs in curvilinear motion.

KEY WORDS: running, curve kinematics, asymmetry, footstike, turf

INTRODUCTION: Previous analysis of locomotion has taken place in a linear path overground, or on a treadmill. Investigations have focused on descriptive kinematics, particularly differences in technique at a range of speeds, and have been well documented by Cavanagh (1990). However, many field and court sports incorporate non-linear movements of cutting, turning and pivoting at different speeds and angles that are typically situation dependent, and make the standardisation of these movements difficult. Intuitively, it would seem that underpinning successful non-linear movements is the ability to sustain movement in a curvilinear path. Also for investigative purposes, curvilinear motion represents a reproducible activity with which games players are familiar.

Hamill et al. (1987) collected ground reaction force data at the inside and outside limbs during athletics bend running. The authors claimed that the outside limb generated greater vertical force than the inside limb. Previous research by McMahon and Greene (1979) into curvilinear motion has yielded early kinematic studies of athletes at maximum speed during various grades of curvature on natural turf. The authors stated that neither step length, or frequency altered appreciably as a function of curve radius. However, no data was presented to verify these claims. Values of top speed, ballistic airtime, and ground contact time were all reported to change dramatically as the grade of curve became tighter. Yet as speed values were not constant, it is difficult to relate adaptations in other variables purely to the altered grade of curvature. Greene (1985) performed further trials on curves of tighter radii, this time on a concrete surface, and suggested that foot contact time increased as radius decreased.

Work by Stoner and Ben-Siri (1979) contradicted the assumptions of McMahon and Greene (1979) when looking at the acceleration phase in sprinting on straight and curvilinear paths. They concluded that stride length decreased significantly, coinciding with a trend for increased running times. Smith et al. (1997) presented findings agreeing with Stoner and Ben-Siri (1979) in contradicting the assumptions made by McMahon and Greene (1979) and Greene (1985) by suggesting a stride length reduction as the curve radius became smaller. Smith et al. (1997) also showed that duration of muscle activity increased around the stance phase during curvilinear motion, which would suggest that the stance phase could illustrate the key adaptations between straight and curvilinear motion. Therefore, the present study aimed to show differences in foot contact time at the inside and outside leg of a curve, during paths of different radii. In addition, the division of total foot, rearfoot and forefoot contact times was investigated to gain an insight to possible differences in footstrike between the two limbs during curvilinear motion.

METHODS:

Subjects: Eight male subjects familiar with curvilinear soccer movements volunteered for the study (Age 27.1 ± 4.7 years). Each subject had foot size equivalent to UK size 9 to enable standardisation of footwear. Each player wore new standard six-stud soccer footwear

(Mizuno, pro-model UK size 9). All subjects were in good health at the time of testing. Ethical clearance and informed consent were obtained and each subject was reminded of their right to withdraw from the study at any time. Testing was performed on natural turf. Turf moisture was assessed using a soil wetness meter (Rapidest, UK), with testing only proceeding if a minimal reading of 3 was attained (range 1-4). This criterion was imposed at a depth of 0.02 m to ensure stud penetration of 0.015 – 0.018 m.

Instrumentation: Foot contact time was measured using two footswitches positioned inside the heel section and under the metatarsal heads of the right boot in a polyurethane insole. The switches were connected to an eight-channel radio telemetry system (MIE Research Ltd. MTR8; Leeds, England) and a yagi aerial transmitted the data from the free roaming subject. Data were sampled as a DC signal from two channels at 500 Hz and recorded on a Viglen 4DX33 personal computer running Orthodata GmbH MYO-DAT 3.0 software for MIE MT8-MBM.

Procedure: Typical radii of curvilinear motion performed in professional soccer were ascertained from notational analysis (Smith et al., 1997). Chosen radii were measured at 5, 10 and 15 metres. Typical jogging and running velocities of soccer players were 4.4 $m.s^{-1}$ and 5.4 $m.s^{-1}$ respectively (Smith et al., 1997). Data were sampled over a five second period. As data were sampled for the right leg, the direction of travel around the curve was again reversed for each condition to enable data capture for both the inside and outside legs of the curve. For comparison, subjects also completed straight jogging and running trials.

Data Analysis: The overall period of the stride cycle was averaged from 6 - 8 strides, with stride length computed from the relation linking subject velocity to the product of stride length and stride frequency. From each trial three typical strides were identified by visual inspection of the data. For each stride, measurements of rearfoot contact, forefoot contact, and total foot contact time were taken by cursor movement in the Orthodata software. A three factor (grade, leg, speed) analysis of variance was performed within each subject to determine differences in the data.

RESULTS: The transition from jogging to running was associated with significant increases in stride length for the inside and outside legs ($p < 0.001$). In the outside leg during running mean values indicated there was a significant reduction in stride length from straight to curvilinear trials ($p < 0.05$), but stride length alterations in the inside leg were not significant.

Adaptation to curvilinear motion was evident at the tightest curvature with a reduction in stride length and an increase in stride frequency and was more clearly evident in running than jogging. Stride length was significantly reduced during running at the 5 m radius ($p<0.001$) than at other grades of curvature and straight motion. However frequency displayed the greatest adaptation to curvilinear motion of the kinematic measures taken.

Table 1 Mean (± S.E.) curvilinear jogging and running temporal parameters while wearing soccer boots (n = 8).

Condition	Stride frequency inside s^{-1}	Stride frequency outside s^{-1}	Stride length inside m	Stride length outside m
straight jog	1.44 ± 0.02	1.44 ± 0.02	3.09 ± 0.05	3.09 ± 0.05
15 jog	1.44 ± 0.02	1.44 ± 0.02	3.05 ± 0.05	3.10 ± 0.05
10 jog	1.42 ± 0.02	1.41 ± 0.02	3.18 ± 0.05	3.14 ± 0.04
5 jog	1.44 ± 0.03	1.47 ± 0.03	3.10 ± 0.06	3.05 ± 0.07
straight run	1.54 ± 0.03	1.54 ± 0.03	3.53 ± 0.05	3.53 ± 0.05
15 run	1.60 ± 0.03	1.60 ± 0.04	3.38 ± 0.06	3.47 ± 0.10
10 run	1.58 ± 0.04	1.56 ± 0.03	3.45 ± 0.07	3.46 ± 0.06
5 run	1.64 ± 0.05	1.70 ± 0.06	3.27 ± 0.12	3.17 ± 0.12

Primarily adaptation occurred at the 5 m radius. Stride frequency was greatest in the outside leg during running at this smallest radius and differed between grade of curve ($p = 0.004$), between inside and outside legs ($p = 0.035$) and with speed of locomotion ($p < 0.001$).
Contact time remained relatively consistent for both legs at all grades of curve when jogging (Figure 1). Figure 1 shows that for the inside leg during jogging, relatively similar rearfoot and forefoot contact times were recorded with increasing curvature. In the outside leg as the curvature became tighter there was a significantly greater rearfoot contact time ($p = 0.003$) than in the inside leg. Although mean forefoot contact time decreased as the curvature became more severe in the outside leg, the trend was not significant statistically ($p = 0.679$). The division of foot contact time always showed the forefoot time to be longer than the heel contact time, except in the outside leg during jogging at the tightest curvature.

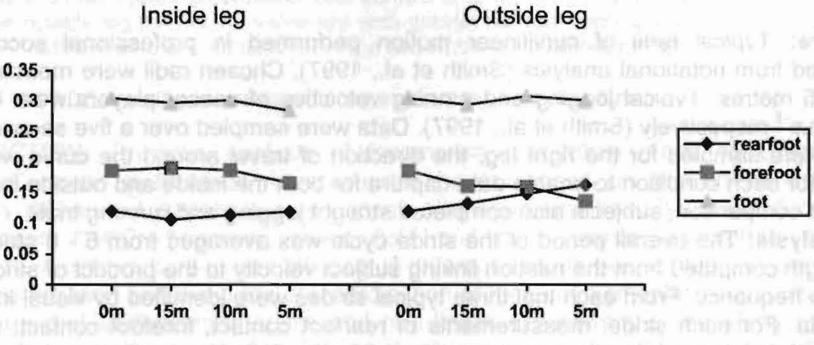

Figure 1 Relationship of heel, forefoot, and total foot contact time whilst jogging.

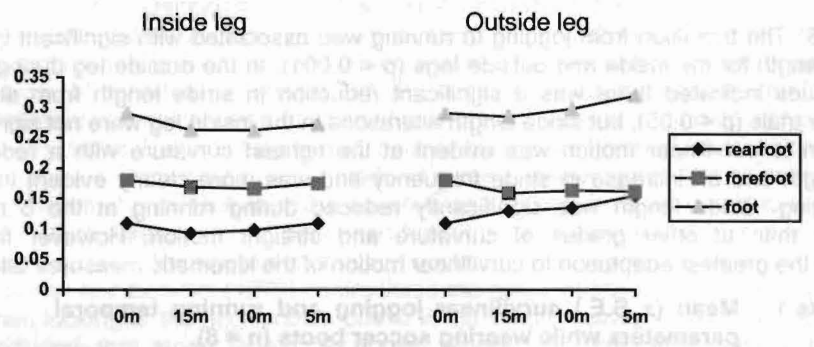

Figure 2 Relationship of heel, forefoot and total foot contact time with curvature whilst running.

When considering jogging and running the increase in movement velocity caused a significant overall reduction in rearfoot contact time ($p = 0.035$) (Figure 1 and 2). Figure 2 indicated that a similar adaptation was evident at the running velocity, where the inside leg showed similar rearfoot and forefoot contact times with increasing curvature. The outside leg showed a significantly greater rearfoot contact time than the inside leg ($p = 0.003$), although forefoot contact time did not differ between legs ($p = 0.405$). There was a strong trend for time of rearfoot contact to increase with increasing curve severity ($p = 0.05$). A significant interaction effect was observed ($p = 0.003$) for the increase of rearfoot contact time at the outside leg as the curve became tighter.

DISCUSSION: The results show that there was significant adaptation to curvilinear motion in jogging and running in both stride length and stride frequency, thus confirming the findings of earlier experiments (Stoner and Ben-Siri, 1979; Smith et al., 1997). However, no significant

adaptation was found with increasing curvature in total foot contact time, or forefoot contact time for the inside or outside leg. In the outside leg there was a significant increase in rearfoot contact time with severity of curvature.
The perceived anomalies observed between these data of no increase in foot contact time and those of Smith et al. (1997) may be explained by referring to the overall difference in stride period. The results presented from the presented study show that the foot contact time does not alter. However, as the stride kinematics tend to reduce the time spent performing each stride, the proportion of the stride cycle spent in contact with the ground will increase. That is, even though the total foot contact time does not increase, the proportional foot contact time does.
The results presented above give rise to a conflict with previous studies in the literature of stride kinematics. Stride frequency was deemed independent of grade of curve by Greene and McMahon (1979) and Greene (1985) yet was shown to alter as a function of curve in the present investigation. An explanation for this could be that the velocity of running in the present study was maintained at discrete values of 4.4 and 5.4 m/s, whereas Greene and McMahon (1979) instructed subjects to run at maximal velocity. Running at maximal velocity might presumably require a maximal stride frequency, which would therefore be essentially independent of radius. Whilst Greene (1985) claimed step length and stride time to be deemed independent of radius, graphical data showed stride length to reduce exponentially as the radius decreases, which would form closer agreement with the present study. Greene and McMahon (1979) found ground contact time to range from approximately 0.12 to 0.20 seconds from 80 feet and 12 feet radius curvature respectively. The contact times in the present investigation range from 0.27 seconds during straight running to 0.32 seconds during running at 5m radius. The differences can be explained by the maximum velocities used by Greene and McMahon (1979) and Greene (1985).
Current work also agreed with findings of Stoner and Ben-Siri (1979), who suggested a different leg action occurs between the inside and outside legs when running a curve, with the outside leg displaying a shorter stride length. Although work by Stoner and Ben-Siri (1979) occurred during the acceleration phase in sprinting, confirmation was gained that a similar adaptation occurred during constant pace curvilinear motion. Adaptation was shown by a decrease in stride length for the outside leg during running ($P < 0.05$) with no corresponding decrease for the inside leg.

CONCLUSION: The investigation into foot contact time using rearfoot and forefoot footswitches showed no increase in foot contact time with tighter grade of curve during curvilinear jogging or running. During running trials, stride length was decreased at the outside leg, but not the inside leg. Such results suggest the technique required for curvilinear motion involves a proportionally increased stance phase, to allow the musculature of the lower limb time to apply the centripetal force necessary for progression in a curved path. In addition the altered proportion of forefoot to rearfoot contact time suggests the two limbs have different functions. The outside foot has greater surface area in contact with the ground during the stance phase, and greater perpendicular displacement to the body centre of mass, and thus would be expected to provide the major contribution to curvilinear motion.

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