ANALYSIS OF NORMAL AND SHEAR FORCES DURING STRAIGHT AWAY AND TURN RUNNING

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INTRODUCTION

The drawing of lane assignments for sprint races involving a curved turn is one of many factors that may help to determine the outcome of a race. The order given to athletes for lane preference is determined by place and time of finish in the' early rounds of competition (NCAA, 1992). A position near the center of the track (lanes 4-5-6) is, for a number of reasons, thought to offer the most favorable condition for success. However, in a race such as the 200-meter sprint, runners negotiate varying degrees of straightaway running and turn running, depending upon the lane drawn. A 0.4 second time differential for 200 meters on a straightaway versus the innermost curve on an Olympic 400-meter track has been suggested (Jain, 1980). Furthermore, Greene (1985) notes a 0.12-second improvement by running in the outermost lane instead of the innermost one. Significant differences for average velocity of sprint starts between straightaway and a 37.72-meter radius curve ($p < 0.05$) have also been demonstrated (Stoner & Ben-Sira, 1979). The staggered start for turn running is meant to equalize differences between lanes. Still, the models presented by Alexandrov & Luctht (1980) and Greene (1985) highlight expected differences in running times with changes in track radii. The added quantity of centripetal force required by the runner to maintain a curved path lends to less economical and slower running. This investigation was conducted to compare impact forces and impulses between (1) three lane conditions and (2) two foot plant conditions.

METHODOLOGY

The subjects were 14 male and female athletes (Mean age = 19.3 yrs) belonging to the Slippery Rock University of Pennsylvania track team. Ten male (Mean hgt = 175.9 cm. and Mean wgt = 70.8 kg) and four female (Mean hgt = 168.1 cm. and Mean wgt = 57.7 kg) college track athletes volunteered for the study. All participants were experienced in both indoor and outdoor competition at the collegiate level. The subjects were selected on the condition that their primary track event(s) required a degree of sprinting ability. Thus, the subjects engaged in one or more of the following events: 100-, 200-, and 400-meter runs, 110m and 400m hurdles, long jump, triple jump, and pole vault.

Data Collection

Force platform. Data acquisition instrumentation consisted of a Kistler Instrument force platform, charge amplifying unit, and a PC-based 386-25MHz microcomputer. The force measurement system and computer were interfaced by a 8-channel junction box with eight BNC connectors from the amp and an analog cable to a 16-channel A/D board in the computer. The Type 9261A multicomponent measuring system was utilized to record the horizontal (Z) shear forces and impulses radial to the direction of movement and the vertical (Y) impact forces and impulses. Force and position were referenced according to the ISB coordinate system. Since turns were negotiated in the counter-clockwise direction. shear force directed toward the center of the track was positive while forces away from the track's center were registered as negative. Downward impact forces were positive. Nominal transducer sensitivities for the horizontal Z and vertical Y forces were 3.65 pC/N and 7.90 pC/N, respectively.

Output voltage range was ±10 V. Charge amp measuring ranges of 10000 pc/10V and 50000 pc/10V were selected for the shear force and normal force, respectively. Data collection was triggered by a minimum 22.24 N (5 lb.) load applied to the platform's surface. Events were monitored for a 1-second duration with an A/D data sampling rate of 250 Hz. Force and impulse data were collected in units of pounds and pound-seconds, respectively, and converted to Newtons and Newton-seconds.

Testing was conducted on the ground floor of the fieldhouse complex in an area designed specifically to accommodate force plate studies. The force plate was bolted to the ground so that its top surface was flush with the gymnasium floor. Three strips of 10 cm. (4 in.) wide non-skid tape were fixed to the'surface of the plate to enhance shoe-to-plate friction since the trials were performed in training shoes. Indoor track lanes were established according to the 200-meter oval specifications in the NCAA Track & Field/Cross Country Rules handbook (NCAA, 1992). The platform rested within a .914-meter (36 in.) minimum width lane at the top of the curve. The inner and outer turn lanes of 18 meters (59 ft., 0.75 in.) and 23.48 meters (77 ft., 0.75 in.), representative of the first and sixth lanes, respectively, were marked by adhering 5.08 cm. (2 in.) wide tape to the track surface. Straightaway lines were such that the lane's orientation was tangential to the curve. The approach for all trials (straight and turn) was measured at 20 meters. The approach was such that the subjects addressed the length axis of the platform. The lanes were extended 6 meters beyond the platform to help guide the subjects and to encourage them to "run through" the platform.

A total of three successful trials for each condition was recorded for each subject. The trials were performed in serial fashion, by subject, i.e., one subject after another. Unsuccessful attempts were repeated until a correct trial was performed. A successful trial was deemed as such if foot placement was executed entirely within the force plate's 40 cm. by 60 cm. perimeter and if the skill was performed with the subject running over the platform with a fluid stride. Subjects were instructed to run in a fast, but controlled, manner. In obtaining the necessary 252 successful trials (i.e., 14 subjects x 3 track conditions x 2 foot conditions x 3 repetitions), 133 other trials were attempted but did not meet the criteria.

Timing. Running velocity was obtained by positioning 2 sets (each with transmitter and receiver) of Lafayette Instrument Co. photocell sensors 2 meters apart on either side of the platform. Timing was performed by a Dekan Model 741A Timing Analyzer, with the clock initialized upon breaking the plane of the first set of cells and stopped by the second set of cells. The obtained times were converted to meters/sec.

Data Reduction

BioWare V2.0, proprietary software by Kistler, was used to analyze the trials. From each force curve the following were determined: contact time, average normal force (Y), average shear force in the side to side direction (Z), and the integral of the area under the force curves, i.e., Y impulse and Z impulse.

RESULTS AND DISCUSSION

A two-factor ANOVA repeated measures design was used to determine the presence of any significant differences for main effect 1 (track condition) and main effect 2 (right/left leg condition). For the three track conditions of straightaway, inside curve, and outside curve, average vertical impact forces and impulses of 1118.05 N and 152.04 N-sec, 1029.73 N and 158.02 N-sec, and 1044.60 N and 155.46 N-sec, respectively, were found to be statistically similar ($p > 0.05$). In addition, only slight differences existed between vertical forces and impulses produced between the legs: 1056.32 N and 155.89 N-sec by the left, and 1071.93 N and 154.45 N-sec by the right.

However, for shear force, differences between track condition--but not leg--were revealed ($F = 47.05$, $p < 0.001$). Shear impulse of force was significant for both main effects, i.e., track condition ($F = 47.41$, $p < 0.001$) and leg condition ($F = 4.71$, $p < .05$). Past-hoc analysis (Scheffe) revealed the source of differences for track condition for both shear force and shear impulse to be between the straightaway running condition and the two forms of turn running. But between the two turn conditions, differences of 73.15 N for average force and 15.63 N-sec for average impulse were not significant ($p > 0.05$).

Because the velocity of running could not be controlled from trial to trial and varied with the centripetal force component during turn running, a repeated measures ANCOVA design was used to analyze, primarily, the results of the two turns. Although it was quite evident that straightaway findings were significantly different from turn running ($p < 0.01$). would use of a covariate-velocity--reveal significant differences in shear force and shear impulse between the two turns? The answer proved to be no. Average velocities of run for the straightaway, inner curve, and outer curve were 7.01 m/sec, 6.55 m/sec, and 6.58 m/sec, respectively. After accounting for velocity, the adjusted mean differences of 73.88 N for force and 15.72 N-sec for impulse between inside curve and outside curve were not significant ($p > 0.05$).

CONCLUSIONS

The primary purpose of this investigation focused upon the magnitude of the normal and shear forces and impulses involved in straightaway and turn running. Of particular importance was the determination of differences, if any, between running a tight turn and a wide turn. Vertical impact forces and impulses proved to be about the same regardless of the 3 lane conditions or the 2 foot plants. However, values for shear force and impulse were significantly different with respect to the lane conditions ($p < 0.001$). But although shear force and impulse were greatest.with the inside lane condition, less in the outside lane, and least on the straightaway, the two turn situations were statistically similar ($p > 0.05$). In analyzing kinetic factors of the plant foot during the turns. the greatest shearing effects were demonstrated with the inside leg, yet not to any degree of significance. Because sprint speeds were wanting due to the difficulty of striking the platform under such controlled conditions, these findings should be limited to "moderate" speed (approximately 7.0 m/sec) running.

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