LOWER EXTREMITY KINEMATICS DURING HIGH SPEED TREADMILL SPRINTING OVER A RANGE OF VELOCITIES

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A kinematic analysis of selected variables was completed during high speed treadmill sprinting over a range of velocities. Six power/speed athletes experienced at sprinting on a treadmill performed trials at 60%, 70%, 80%, 90%, and 95% of their previous individual maximum velocity, with video data collected in the sagittal plane at 60 Hz. The results indicated that there were significant differences among the variables studied, particularly at slower velocities. Peak hip extension and peak knee flexion showed no differences across test conditions. As the treadmill velocity approached a maximum, mechanical breakdown was seen in a decreased maximum hip flexion angle and peak hip flexion angular velocity, suggesting that velocities greater than 90% velocity should be used selectively during treadmill training.

KEY WORDS: kinematics, sprinting, sprint training, treadmill running

INTRODUCTION: Treadmills are important tools for research into human locomotion, as they allow investigators to closely control the testing environment in their studies. This is especially true for high speed running treadmills, whose capability for reaching speeds of 12.5 $m \cdot s^{-1}$, inclines up to 40 degrees, and declines of 10 degrees allow for closely controlled and specified testing under a wide range of conditions. High speed treadmill use as a training tool for speed development has been steadily increasing, despite the fact that studies have found differences between treadmill and overground running (Elliott & Blanksby, 1976; Nelson, Dillman, Lagasse, & Bickett, 1972) and sprinting (Frishberg, 1983).

Overground kinematics of the lower extremity during level sprinting are well documented (Mann, 1985; Mann & Herman, 1985; Mero, Komi, & Gregor, 1992). Overground studies have reported changes in sprint kinematics at a range of velocities from submaximal to maximal (Luhtanen & Komi, 1978). However, no studies have analyzed treadmill sprinting over a range of velocities. With the differences reported in running and sprinting kinematics between overground and treadmill conditions, it is unclear if training is being performed at a velocity which is most beneficial for the athlete and which most closely replicate overground sprint kinematics. Therefore, the purpose of this study was to document the stride characteristics and lower extremity joint kinematics of sprinting on a high-speed treadmill over a range of velocities. Because the goal of sprint training is to maximize horizontal velocity, comparisons were made between various submaximal velocities and the maximal velocity achieved by the participants. It was hypothesized that there would be differences in lower extremity kinematics while sprinting on a treadmill at a range of velocities, as compared to the maximum.

METHODS: Six participants were recruited for this study, all of whom competed nationally or internationally in power/speed events in athletics, and were familiar with sprinting on the high speed treadmill. All subjects volunteered for this study and gave informed written consent to serve as subjects. Mean height was 1.76 $\pm$ 0.01 m for the males and 1.67 $\pm$ 0.05 m for the females. The males and females had a mean masses of 73.8 $\pm$ 5.6 kg and 59.1 $\pm$ 5.5 kg, respectively.

After completing their individual warm-up, each subject was fitted with reflective markers (diameter = 0.02 m), which were located on the joint centers of the hip (greater trochanter), knee (lateral epicondyle), ankle (lateral malleolus), heel (middle of calcaneus) and foot (base of fifth metatarsal) on the side facing the camera.

Trials were completed on an Acceleration® high speed running treadmill set at zero degrees of inclination. Each participant completed runs of 60%, 70%, 80%, 90%, and 95% of their individual maximum velocity on the treadmill, which had previously been established during training. The treadmill was preset to a specific velocity for each individual prior to the trial; there was no acceleration or deceleration phase. For each trial three successive strides were analyzed, which was consistent with previous treadmill studies (Nigg, de Boer, & Fisher, 1995; Sinning & Forsyth, 1970). A stride was defined as the time from ground contact of one foot to ground contact of the same foot.

Video data of the sagittal plane motion was collected using a Canon 8mm video camera, which recorded at 60 Hz and a shutter speed of 1/2000. The camera was located such that the optical axis was perpendicular to the plane of movement. Data processing was completed using an Ariel Performance Analysis System. For each trial, the time-dependent coordinates of each landmark were smoothed using a low-pass digital filter with a cutoff frequency of 8 Hz to reduce small random errors that may have occurred during digitizing, without introducing systematic bias. The cutoff frequency was determined by inspection of the raw and filtered data and comparison between the respective power spectra. Ensemble averages were calculated across all subjects under each condition for all variables.

Descriptive statistics (means (M) and standard deviations (*s*)) were calculated for variables selected for analysis based on previous sprint studies. Differences between the test conditions were analyzed using a one-way repeated measures analysis of variance (ANOVA). Post hoc tests were used to determine where differences were seen among the 60%, 70%, 80%, and 90% velocities in comparison to the 95% test condition. Probability values less than 0.05 were taken to indicate statistical significance.

RESULTS AND DISCUSSION: Mean treadmill velocities and stride characteristics are reported in Table 1. Stride frequency was seen to increase systematically as the treadmill velocity increased, and was a result of decreases in the length of both stance and flight phases. These results counter with some previous studies of treadmill running. Nelson et al. (1972) found that treadmill running displayed a decreased stride frequency with an increased support phase as compared to overground running. Elliott and Blanksby (1976), on the other hand, reported that an increased stride frequency was the result of a decreased non-support phase with no change in the support phase for the treadmill running mode as compared to overground. These previous studies, however, were at velocities slower than the present study. Luhtanen & Komi (1978) showed increases in stride frequency as overground sprinting velocity increased from submaximal to maximal for male track and field athletes. These authors also reported decreases in flight and support time with increased velocity. These results are in agreement with those of the present study, showing that when there are increases in sprinting speed either on the treadmill or overground, there is an increase in stride frequency which is a result of a decrease in both flight and stance times.

Table 1 Treadmill Velocities and Stride Characteristics

Treadmill Velocity (% Maximum)	Treadmill Velocity (meters•sec^{-1})	Stride Frequency (strides•sec^{-1})	Stance Time (msec)	Flight Time (msec)
60%	6.3 ± 0.7	1.7 ± 0.1[b]	140 ± 10[b]	160 ± 10[b]
70%	7.3 ± 0.8	1.9 ± 0.1[b]	130 ± 10[b]	140 ± 10[b]
80%	8.4 ± 0.9	2.1 ± 0.1[b]	110 ± 10[b]	130 ± 10[a]
90%	9.4 ± 1.0	2.2 ± 0.1[a]	100 ± 10[a]	120 ± 10
95%	9.9 ± 1.1	2.3 ± 0.1	90 ± 10	120 ± 10

Values represent Mean ± SD across subjects
[a] mean significantly different from 95% velocity ($p < 0.05$)
[b] mean significantly different from 95% velocity ($p < 0.01$)

Table 2 shows the kinematics of the hip while sprinting on a treadmill over a range of velocities. Peak flexion of the hip was significantly smaller at the two slowest test conditions, but was seen to increase as treadmill velocity increased and reached a maximum value at 90%. The 95% value, however, was slightly smaller than at 90%, which is not ideal. Mann and Herman (1985) have stated that maximizing flexion of the hip is crucial in producing the necessary upper leg angular velocity prior to and during ground contact. Mean hip flexion angular velocity was also significantly slower at 60% and 70%, and showed a similar trend in which the highest angular velocity value was seen at the 90% velocity. These results are clearly related. The degree of hip flexion is associated with the velocity with which it is being flexed. At near maximum treadmill velocities, the sprinter is unable to continue increasing the hip flexion angular velocity of the recovery leg, and must restrict the hip range of motion in order to maintain the high cadence and make proper ground contact.

Table 2 Hip Kinematics During Treadmill Sprinting over a Range of Velocities

Treadmill Velocity (% maximum)	Hip Flexion (°)	Hip Extension (°)	Hip Flexion Angular Velocity ($°\cdot sec^{-1}$)	Hip Extension Angular Velocity ($°\cdot sec^{-1}$)
60%	56 ± 5^b	-21 ± 3	549 ± 60^b	-469 ± 51^b
70%	60 ± 5^b	-21 ± 3	634 ± 44^b	-523 ± 46^b
80%	62 ± 5	-21 ± 4	696 ± 76	-569 ± 71^b
90%	67 ± 7	-21 ± 5	727 ± 46	-626 ± 57
95%	67 ± 8	-22 ± 6	726 ± 51	-666 ± 53

Hip extension angular velocity was significantly smaller at the three slowest test conditions, but was seen to increase as treadmill velocity increased. Mann et al. (1982-1983) found that larger the hip extension angular velocities prior to and during ground contact result in smaller ground contact times. The results of this study may indicate that one of the strengths of training at near maximum velocities on a high-speed treadmill may be in increasing hip extension angular velocity. After toe-off, the maximum angle of hip extension showed no significant differences among the velocities tested, which is a desirable characteristic of sprinters as it minimizes ground contact time and makes leg recovery as efficient as possible (Mann, 1985).

Table 3 shows the kinematics of the knee while sprinting on a treadmill over a range of velocities. There were no significant differences in the maximum angle of knee flexion, as seen during the recovery phase, at any of the velocities. According to Mann (1985), better sprinters minimize the lower leg angle during recovery to make the task of recovering the leg both faster and easier. Significant differences were seen in the angle of knee extension seen at toe-off at the slowest treadmill velocity, with no significant differences seen at the other velocities. Knee flexion and knee extension angular velocity were significantly smaller at the three and two slowest treadmill conditions, respectively, as compared to the maximum. This suggests that as

Table 3 Knee Kinematics During Treadmill Sprinting over a Range of Velocities

Treadmill Velocity (% maximum)	**Knee Flexion (°)**	**Knee Extension at Toe-off (°)**	**Knee Flexion Angular Velocity ($°\cdot sec^{-1}$)**	**Knee Extension Angular Velocity ($°\cdot sec^{-1}$)**
60%	45 ± 7	149 ± 2^a	-786 ± 61^b	939 ± 93^b
70%	43 ± 5	146 ± 5	-844 ± 98^b	1016 ± 101^b
80%	41 ± 5	143 ± 7	-950 ± 54^b	1121 ± 132
90%	40 ± 6	142 ± 7	-1058 ± 101	1156 ± 132
95%	42 ± 6	142 ± 8	-1083 ± 119	1165 ± 119

the treadmill velocity increases, sprinters attempt to limit the lower leg range of motion in order to minimize the ground contact time, and to enable the leg to recover fast enough for the next ground contact, a finding which is consistent with previous work (Mann, 1985).

CONCLUSION: The benefits of the high-speed treadmill for the development of the various metabolic systems important to sprinting success are unquestionable, particularly in the long sprint events. There are also a number of mechanical benefits to running at near maximum velocity on a high-speed treadmill, including decreasing support and non-support time, and increasing hip extension angular velocity. However, the mechanical breakdown in peak hip flexion and peak hip flexion angular velocity seen at near-maximum velocities suggests that sprinters incorporating a high speed treadmill as part of their training regimen should use a velocity of 90% of their individual maximum on the treadmill as their velocity for speed development. Speeds greater than 90% should be used selectively as they may develop unwanted technical adaptations, and should be coupled with overground training to properly develop the physiological factors important to maximum speed sprinting.

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