KNEE JOINT KINEMATIC VARIABILITY OF THE TOUCHDOWN LEG DURING THE MAXIMAL VELOCITY PHASE OF SPRINT RUNNING

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This study aimed to develop insight into knee joint kinematic variability of the touchdown leg during the maximal velocity phase of sprint running. Joint centre coordinate data were obtained for running trials performed by seven male athletes. Between and within athlete coefficient of variations were derived for step and sagittal plane knee joint angle variables. The minimum knee joint angle produced the largest between (13.3%) and within (8.4%) athlete variability and was related to velocity by an inverted U profile. The slowest and fastest athletes produced relatively higher step velocity variability than the intermediate athletes. The discrepancy in the within athlete step and knee joint kinematic variability of performers achieving similar gait-related objectives suggested a need to consider idiosyncratic kinematic patterns in developing sprint running performance.

KEY WORDS: performance, step characteristics, athlete-specific.

INTRODUCTION:

Insights into the biomechanical responses made in running gait have typically been achieved through quantitative comparisons of the kinematical variations produced between distinct gait modes e.g. distance and sprint running or within gait mode velocities e.g. sub-maximal and maximal running. The extent and patterning of the knee joint action used has frequently differentiated running gait modes. Novacheck (1998) highlighted that similar knee motion patterns, defined by the timing of discrete motion events within the respective gait cycles, were used in running and sprinting but larger extremes of knee motion e.g. the amount of swing phase knee flexion were evident with increasing speed. More recently, Kivi, Maraj and Gervais (2002) suggested that maximum knee flexion and extension at toe off did not differ between sub-maximal and maximal treadmill running but knee extension angular velocity did vary significantly between cadences. Further insight into the variations in lower limb kinematic patterns made by, and between individuals to satisfy the same gait objective but with marginally differing outcomes have however been contradictory.

Within competitive running, velocity discrepancies may lead to small but critical deviations in an individual's subsequent performance outcome. Variations in maximal running velocity have been attributed to the production of group and individual changes to the mechanical response made across the gait mode. Krell and Stefanyshen (2006) recently highlighted that the kinematics of the lower body play an important role in sprint running but the contribution of each joint of the lower limb to performance remains unclear. Weyand et al. (2000) contrastingly suggested that variations in top speed treadmill running were achieved by increasing support forces with the ground rather than repositioning limbs more rapidly. However, McKenna and Riches (2007) further suggested that maximal velocity running is attained using a kinematic pattern, which is idiosyncratic to an individual. Kivi, Maraj and Gervais (2002) further suggested greater variability in the hip and knee joint position at maximal velocity compared to sub-maximal velocity running.

Developing insight into the lower body kinematic variability achieved in sprint running has the potential to enhance insight into the mechanical factors defining sprint running and the subsequent limits of running performance. The aim of this study was therefore to develop understanding of the variability in knee joint kinematics of the touchdown leg during the maximal velocity phase of sprint running performances.

METHOD:

Seven male sprint runners (mean ± SD: age: 20.43 ±0.93 years; mass: 80.54 ±11.70 Kg; stature: 1.851 ±8.03 m), who were of regional or national standard, were recruited for the study. The University's Research Ethics Committee gave approval for the data collection and each athlete gave written informed consent.

Each athlete performed four sprint running trials (approximate distance of 70 m) on a 110 m Mondo track located in a national indoor athletics centre. Subjects were asked to maintain a constant sprint running velocity for as long as possible following acceleration from a standing start. Active markers were located on the lateral, left side of each athlete at the distal end of the fifth toe and on the ankle, knee, hip and shoulder joint centres. Markers were also located on the distal end of the first toe and the ankle and knee joint on the medial side of the right leg. Three co-aligned CODA CX1 motion analysis scanners (Charnwood Dynamics Ltd., Leicestershire, UK) were located unilaterally 6.0 m apart and 4.2 m from the centre of the running lane (sample rate: 200 Hz) to obtain active marker locations for a 10 m distance (between 40 m and 50 m) in the direction of each sprint running performance.

The three-dimensional coordinate data were reduced to two-dimensions (2D) (z-vertical and y-anterior-posterior) and low-passed filtered at 15 Hz. Knee joint flexion-extension angle-time profiles were determined for each trial using the filtered 2D joint coordinate data. Individual steps were defined in each trial using the vertical acceleration data of the toe marker of the touchdown leg to identify initial ground contacts (touchdown). A single step was defined between contra-lateral foot touchdown events. Step length [SL: y displacement between successive touchdown foot marker locations], frequency [SF: 1/time between successive touchdowns], frequency: length ratio [SFLR: SF/SL] and velocity [SV: SL/(1/SF)] were determined for each individual step.

A minimum of three steps was obtained for each trial and the trial-specific velocities of successive steps were examined to ensure that athletes were not progressively accelerating during the data collection volume. Two steps initiated with the same touchdown leg were selected for further analysis and the step-specific initial, minimum, maximum and range of motion of the touchdown leg knee joint angle were determined. Within and between athlete coefficient of variations in the step and knee joint discrete variables were calculated as the standard deviation of the respective data set divided by the corresponding mean.

RESULTS:

A higher between athlete variability was found for all step characteristics and for the minimum, maximum and range in the knee joint flexion-extension angle (Table 1) compared to the within athlete variability. The largest between (9.5%) and within (4.8%) athlete variability in the step kinematics occurred within the SFLR while the minimum knee angle of the touchdown leg was associated with the greatest between (13.3%) and within athlete (8.4%) variability for the knee joint variables.

Table 1 Between and Within Athlete Coefficient of Variation (%) in Discrete Step and Knee Joint Angle (Flexion-Extension) Characteristics of the Touchdown Leg

	Step Characteristics (%)				Knee Joint Flexion-Extension Angle (%)			
	SL	SF	SFLR	SV	Initial	Min	Max	Range
Between	4.3	5.9	9.5	3.9	1.3	13.3	9.5	10.0
Within	2.0	3.1	4.8	2.5	2.5	8.4	4.9	1.5

As illustrated in Figure 1a, within athlete variability in SF increased with mean athlete velocity such that the variability of the slowest (mean velocity: 8.41 $m \cdot s^{-1}$) and fastest athlete (mean velocity: 9.37 $m \cdot s^{-1}$) was 1.8% and 5.6%, respectively. Athletes achieving the slowest and fastest mean velocity produced relatively greater within athlete SV variability compared to those achieving intermediate velocities.

The lower variability in the SV of the intermediate athletes was typically associated with relatively greater variability in the initial, minimum and range of motion in the knee joint angle of the touchdown leg (Figure 1b). For example, within athlete variability in the minimum knee joint angle was 4.5% and 6.0% for the slowest and fastest athlete and 14.7% for an athlete achieving an intermediate velocity (8.96 $m \cdot s^{-1}$).

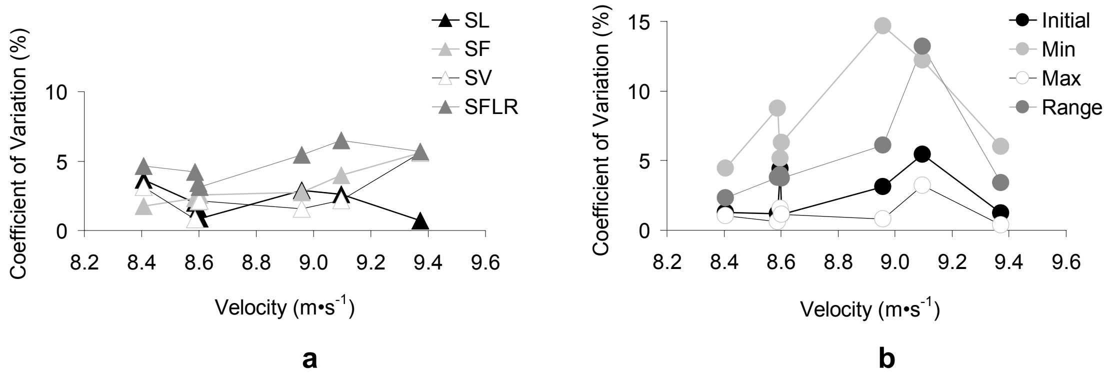

Figure 1: Within Athlete Coefficient of Variation (%) in a. Step and b. Knee Joint Angle (Flexion-Extension) Characteristics Relative to Athlete-Specific Mean Velocity Across All Steps.

DISCUSSION:

The between and within athlete variability in knee joint kinematics and the associated step responses for the maximal velocity phase of sprint running performances were investigated. The minimum knee joint angle of the touchdown leg produced the largest between and within athlete variability for the running trials. The presence of a high between and within athlete variability in the minimum knee joint angle suggested the degree of knee flexion used during the step phase to be a potentially important indicator of the achievement of consistent high-level top speed running.

The slowest and fastest athletes produced high within athlete variability in the SV with an associated low variability in the discrete knee joint angle variables (initial, minimum and range). The relatively greater variability in the performance-related outcome (SV) of the faster and slower athletes suggested the use of a flexible performance-driven control strategy that may allow adaptation to external and internal constraints in sprint running. For the faster athletes, high variability in SV was associated with high SF variability which contrasted to the high SV and low SF variability of the slower athletes. The contrasting levels of SF variability associated with the extreme performers suggested that the slowest and fastest athletes within the high-level sprint performance group selected a similar performance-driven control strategy formulated by velocity-dependent contributions from step frequency.

The contrasting lower performance-related variability of the intermediate athletes with a higher variability in the knee joint angle characteristics suggested that, unlike their faster and slower counterparts, the intermediate athletes may have minimised performance variability through the presence of greater flexibility in the knee joint patterning at key phases. Bradshaw, Maulder and Keogh (2007) suggested an attempt in recent research to produce a relatively invariant biomechanical model for sprint running. The variability discrepancies in the step and knee joint variables produced by performers aiming to achieve similar gait-related objectives supported the suggestion of McKenna and Riches (2007) that the kinematic pattern used to attain maximal velocity running is idiosyncratic to an individual. The findings of this study therefore supported the integration of performer-specific technique developments into sprint running training.

Within athlete variability in the knee joint kinematic characteristics was typically associated with the mean sprint velocity of the athlete by an inverted U-shaped profile. Wilson et al. (2008) suggested a contrasting U-shaped relationship between joint kinematic variability and skill level in triple jumpers. Unlike the single joint analysis addressed in this investigation, Wilson et al. (2008) examined joint coordination variability. The relatively lower knee joint kinematic variability of the slower and faster athletes examined in this investigation may therefore be attributed to a more variable joint coordination strategy across the lower extremity, which utilised a more consistent knee joint motion than the intermediate athletes.

However, further examination of the joint coordination strategies used in sprint running are required to confirm the potential control mechanism used by the more extreme performers.
A comparison of individual joint kinematic variability in maximal and sub-maximal velocity treadmill running found contrasting increases in knee joint positional variability at the faster velocity (Kivi, Maraj & Gervais (2002). The partial discrepancy in knee joint variability reported in the investigation examining between (Kivi, Maraj & Gervais, 2002) and within running mode responses (this investigation) further supports the need to consider the role of idiosyncratic movement pattern variability within differing gait modes and the subsequent influence on performance-related outcomes. Future research aims to examine joint kinematic patterning and variability between sprint running phases e.g. acceleration and maximal velocity and varying running modes e.g. distance and sprint running in order to develop further insight into the lower body biomechanical contribution to the control of running gait.

CONCLUSION:

A high between and within athlete variability in the minimum knee joint angle in the maximal velocity phase of sprint running indicated the potential role of discrete events of the knee joint kinematic pattern in satisfying the same running gait objective but with marginally differing performance outcomes. Consistent sprint running performance was related to a flexible knee joint kinematic pattern at discrete events but was not necessarily associated with the most successful performances. The need to consider performer-specific, lower body joint kinematic patterns used to develop sprint running performance was highlighted.

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