ATHLETE-SPECIFIC ANALYSES OF LEG JOINT KINETICS DURING MAXIMUM VELOCITY SPRINT RUNNING

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The effect of variations in joint kinetics on sprint performance in individual athletes is not yet known. To investigate biomechanical contributions to maximum velocity sprint running, data were collected from one elite male sprinter performing maximum effort 60 m sprints. High-speed video (200 Hz) and ground reaction force (1000 Hz) data were collected at the 45 m mark. Horizontal velocity and joint kinetics, via inverse dynamics, were calculated for two trials. The velocity of the step was closely linked to step length, knee angular velocity before touchdown, peak-to-peak centre of mass oscillation, hip extension moment during stance and ankle positive work before take-off. The study revealed the potential for athlete-specific, detailed biomechanical analysis and feedback to aid the technical work of athletes and their coaches across a range of sporting skills.

KEY WORDS: track and field athletics, intra-subject variation, inverse dynamics analysis

INTRODUCTION:

The study of joint kinetics can improve the understanding of the underlying causes of a movement (Winter, 2005). Biomechanical investigations of sprint running have studied the joint kinetics of the movement, but a comprehensive understanding of its causative mechanisms has not yet been achieved. To date, several studies have presented group-level analyses of the importance of joint kinetic factors to sprint performance (e.g. Mann, 1981; Johnson & Buckley, 2001; Belli et al., 2002). One possible approach to increasing understanding is to investigate the factors that relate to performance on a within-subject basis: examples from sprinting include Weyand et al. (2000) and Hunter et al. (2004), although these have only reported joint kinematics and ground reaction forces, and have not extended to joint kinetics. Recently, individual athlete results for joint kinetic variables have been presented (Bezodis et al., 2007; 2008), but a detailed analysis on an individual level in order to highlight the kinematic and kinetic variables that are most important to sprint performance has yet to be presented. Analysing and communicating these data sets in this manner would greatly help elite coaches with the development of specific individualised technical training programs that would allow athletes to focus on the development of targeted biomechanical variables with the explicit goal of improving sprint performance. The aim of this study, therefore, was to understand and summarise the individual biomechanical factors that contribute to changes in sprint performance between runs in an elite sprinter.

METHODS: Data collection: One elite male sprinter (height: 1.76 m; mass: 74.9 kg; 100 m PB: 9.98 s) with no recent injuries gave written informed consent to participate. Data were collected in the National Indoor Athletics Centre, Cardiff in late November. A force plate (9287BA, Kistler Instruments Ltd., Switzerland) operating at 1000 Hz was placed in a customised housing in the centre the track, and covered with a secured piece of the synthetic track surface. A high-speed camera (resolution 768 x 604 pixels; Redlake, MotionPro HS-1, USA) was placed perpendicular to the direction of the sprint, 25.0 m from the centre of the lane, with a 3.0 m field of view centred on the force plate. The high-speed camera was set up with a frame rate of 200 Hz, a shutter speed of 1/600 s, and was manually focussed. A 50 Hz digital video camera (DCR-TRV 900E, Sony, Japan) was located 3.5 m above the track surface, 6.3 m away from the centre of the running lane and 1.5 m before the centre of the force plate to give a field of view of 6.5 m in the direction of the running lane. The 50 Hz camera was set up with a shutter speed of 1/600 s, and was manually focused. Images of a 6-point sagittal plane calibration object were captured with each camera before the start of the running trials. A single synchronisation unit was used to link the cameras with the force plate. The area around the force plate was illuminated with 7600 W of floodlighting.

A customised starting check mark was located approximately 45 m before the force plate. This was used to aid the athlete in striking the force plate without the need to alter technique in the steps immediately preceding force plate contact (targeting). The athlete performed six 60 m sprints, consisting of a 30 m build up followed by a timed ‘flying 30 m’, within which the force plate was centred. A trial was deemed successful if the participant was able to strike the force plate at maximum velocity without noticeably or consciously altering his stride pattern. Two successful trials (labelled 1A and 1B) were achieved from the six runs.

Data Processing: Video data from the 50 Hz camera were imported into Target (Loughborough Innovations Limited, UK) and digitised using a 20-point model, comprising shoulder, elbow, wrist, fingertip, hip, knee, ankle, head of the second metatarsal and toe on each side of the body, and top of the head and base of the neck. Video data from the high-speed camera were imported into Peak Motus (v8.1.4.0, Peak Performance Technologies, Inc. USA), and digitised using a 5-point model, comprising head of the second metatarsal, and the ankle, knee, hip and shoulder joint centres on the side of the support (right) leg. All digitised coordinates were reconstructed using the 2D-DLT with lens correction (Walton, 1981). Trial 1A was digitised three times, on separate days, to examine the effect of digitising errors. Horizontal velocity, step length and step frequency of the step from the force plate in each trial were calculated using the information taken from the 50 Hz camera, as described by Bezodis et al. (2008). The step cycle was defined from the instant of touchdown on the force plate to the subsequent contact of the contra-lateral foot.
Vertical and horizontal ground reaction forces and coordinates of all digitised points from each camera for each successful trial were subjected to a residual analysis in order to determine optimum cut-off frequencies (Winter, 2005). Once filtered at the respective optimum cut-off frequencies, the ground reaction force data were matched to a video frame from the high-speed camera and were extracted at 200 Hz. However, the instant of touchdown was identified using the 1000 Hz force data. Body segment inertia parameters were taken from de Leva (1996) with the exception of the foot segment, for which data were taken from Winter (2005). The mass of a typical sprinting shoe (200 g) was added to the mass of the foot segment (Hunter et al., 2004). Joint moments, power and work were calculated by standard inverse dynamics equations, as presented by Winter (2005), then normalised (Hof, 1996). Three other well-trained sprinters from the same training group had also given written informed consent to take part in the same data collection and each achieved two successful trials. For interest, to facilitate the presentation of results to the athlete and coach all variables were calculated as a percentage of the group mean for each individual variable.

RESULTS: The athlete ran two steps at over 10 m/s, showing that this testing session was conducted at a true elite performance level. There was a difference in velocity between the two steps of 0.23 m/s. Results (in table 1) showed that the faster of the two trials yielded several variables that were markedly greater in magnitude than the slower of the trials. These included: step length, knee angular velocity before touchdown, peak-to-peak centre of mass oscillation, hip extension moment during stance and ankle positive work before take-off.

Pilot testing revealed that step variables could be measured to within the following RMS differences of a known criterion; 0.02 m/s for velocity, 0.01 m for step length and 0.01 Hz for step frequency. An error analysis of joint moments and work revealed intra-trial variability to be between three and twelve times greater than differences arising from repeat digitisations of a single trial. Figure 1 shows data as percentage of the group mean (the bars correspond to the respective variables from table 1).

Table 1 Selected kinematic and kinetic results for each trial.

Variable	Trial 1A	Trial 1B
Step velocity [m/s]	10.37	10.14
Step length [m]	2.25	2.17
Step frequency [Hz]	4.62	4.68
Knee angular velocity at TD [rad/s]	-4.80	-3.60
Ground contact time [s]	0.097	0.095
Maximum vertical force [BW]	4.41	4.39
Peak-to-peak CM oscillation [m]	0.057	0.047
Peak knee flexion moment after TD	-0.210	-0.212
Peak hip extension moment after TD	0.636	0.615
Peak hip extension moment in stance	0.299	0.276
Ankle positive work before take-off	0.064	0.040

Note: Joint kinetic variables have been normalised by body weight and height (Hof, 1996): TD = touchdown.

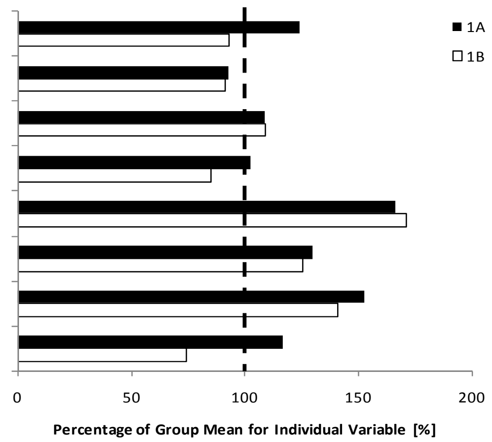

Figure 1 Selected results for each trial, presented as a percentage of training group mean.

DISCUSSION:

The running velocity achieved by the athlete in this study was greater than that of participants in previous studies of joint kinetics in maximum velocity sprinting (Mann, 1981; Belli et al., 2002). Step length values were lower and step frequency higher than previously reported findings from elite sprinters (Mann and Herman, 1985).

The aim of this study was to understand and summarise the individual biomechanical factors that contribute to changes in sprint performance between runs in an elite sprinter, and to present this information to the athlete and his coach. In order to represent complicated biomechanical variables in a manner that could be readily understood by the practitioners, specific variables other than step velocity, length and frequency were presented as a percentage of the mean value of that variable from the training group of four athletes. These relative values, along with an explanation of the meaningfulness of each specific variable facilitated understanding of complex technical data for the coach and his training group.

In trial 1A, the faster of the two measured, the knee flexion velocity at touchdown was over 20% above the group mean. This showed that the athlete was rapidly 'clawing' at the track and adopting a suitable position for the production of force during the stance phase (Mann and Herman, 1985). The combination of a below group average contact time and above group average maximum vertical force in the athlete studied displayed a method of generating impulses during stance that has been shown to be beneficial to sprint performance (Weyand et al., 2000). The vertical impulse during stance dictates the change in vertical velocity and therefore the peak-to-peak vertical oscillation of the centre of mass throughout the measured step. In trial 1B, the oscillation was 15% below the group mean, resulting in a reduced step length and therefore a reduced step velocity. The three joint moment values presented here ranged from 30-71% above group mean in both trials, giving a good reflection of the overall muscular strength that the athlete possessed. The athlete 'pulled' himself rapidly over the contact foot after touchdown, reducing the braking effect in early stance, by the large knee flexion and hip extension moments, which have been shown to be crucial to sprint performance (Mann and Sprague, 1980). The large hip extension moment later in the stance phase acted to drive the body over the contact foot and help to restore the forward momentum of the body. The magnitude of positive work performed at the ankle joint has previously been shown to be linked to sprint performance (Bezodis et al., 2007), and in this athlete was over 40% of the group mean greater in trial 1A than 1B. This value gives a very good indication of the overall propulsion of the step, but occurs as a result of transfer of the propulsive forces from the larger proximal muscles by the bi-articular muscles of the leg.

CONCLUSION: This study has demonstrated athlete-specific analysis of joint kinetics during a sprint run that was previously suggested by Bezodis et al. (2007). The results could provide detailed biomechanical feedback to a coach and his athletes in a readily understandable manner that can facilitate the development of specific technical training programs designed to improve sprint performance. Whilst this study used two trials, a larger sample size for each athlete would improve the validity of the results, although this can be difficult to achieve in a practical setting. This athlete-specific analysis has the potential to improve the practitioner understanding of complex biomechanical concepts and could also be readily applied to a number of other sporting skills.

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