JOINT KINETICS IN MAXIMUM VELOCITY SPRINT RUNNING

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The effect of variations in joint kinetics on step characteristics and velocity is not yet known. To investigate contributions from the ankle, knee and hip to maximum velocity sprint running, data were collected from four well-trained male sprinters 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 in each athlete. The magnitude of positive work performed by the ankle joint during the propulsive phase of stance was closely linked to the velocity of the step, and thought to be the result of a coordinated leg action during the support phase. The study revealed the potential for athlete-specific biomechanical analyses to aid the technical work of athletes and their coaches.

KEY WORDS: track and field athletics, joint work, inverse dynamics analysis, variation

INTRODUCTION:

Velocity is the product of step length (SL) and step frequency (SF), and both have been shown to vary on an intra-subject, inter-trial basis (Vardaxis & Hoshizaki, 1989; Hunter et al., 2004a). Furthermore, SL and SF are themselves determined by the many kinematic and kinetic variables that make up sprint technique. Several studies have been carried out attempting to identify those kinematic and kinetic variables that are important to performance (e.g. Mann, 1985; Weyand et al., 2000). Although attempts have been made to link these variables to SL and SF (Hunter et al., 2004b), there is still no research available that has examined the effect of joint kinetics on variations in velocity. Analysing the simultaneous changes in joint kinetics and kinematics, and ultimately the variations in velocity over a series of steps, will give an insight into how the joint kinetics affect performance. Examination of these effects will lead to greater understanding of the critical determinants of maximum velocity sprinting in highly-skilled athletes. To date, studies have adopted an intra-subject approach to investigating critical factors in sprint running (Weyand et al., 2000; Hunter et al., 2004b), and also investigated joint kinetics in sprinting (Mann, 1981; Johnson & Buckley, 2001; Belli et al., 2002), but none have studied both simultaneously. The primary purpose of this study was to identify the effect of variations in joint kinetics on sprint velocity.

METHODS:

Data collection: Four well-trained male sprinters gave written informed consent to participate in this study. Subject information for the four athletes is shown in Table 1. All subjects were fit and healthy at the time of data collection, and reported no recent injuries.

Table 1 Subject Information *Event personal best times (PB) are for (1)100 m and (2)200 m.

Subject ID	Height [m]	Mass [kg]	Event	Event PB* [s]
1	1.76	74.9	100 m	9.98 (1)
2	1.84	79.2	Decathlon	10.91 (1)
3	1.70	64.1	200/400 m	23.67 (2)
4	1.83	82.4	200/400 m	21.25 (2)

Data were collected in the National Indoor Athletics Centre, Cardiff in late November. A force plate (Kistler Instruments Ltd., 9287BA, 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 to preserve ecological validity. 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, an open iris with no gain 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, an automatic iris 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 for each athlete 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). Each 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 athlete was able to strike the force plate at maximum velocity without noticeably or consciously altering his stride pattern. Each athlete achieved two successful trials 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 included. Trial 1A was digitised three times, on separate days, to examine the effect of digitising errors. Horizontal velocity, SL and SF of the one step from the force plate in each trial were calculated using the information taken from the 50 Hz camera. The step cycle was defined as beginning with the instant of touchdown on the force plate, and finishing with the subsequent contact of the contra-lateral foot. Velocity was calculated as the horizontal displacement of the whole body mass centre from one foot contact to the next (where the position at each individual contact was taken as the mean values at the last field of flight and the first field of support) divided by the time between the two contacts. The SL was calculated as the displacement between the toe points in the first field after touchdown in two consecutive steps, and SF was calculated as the velocity divided by the SL.

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 the optimum cut-off frequency (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., 2004a). Joint moments, power and work were calculated by standard inverse dynamics equations, as presented by Winter (2005), and were divided by the individual athlete’s body mass to allow comparison between the athletes.

RESULTS:

Two subjects (1 and 4) ran steps of velocities differing by at least 0.23 $m{\cdot}s^{-1}$, whilst the other two subjects ran steps that differed by only 0.01 $m{\cdot}s^{-1}$ (Table 2.). Intra-subject changes in SL ranged from 0.01 to 0.09 m, with the largest variation in subjects 1 and 3, whilst intra-subject changes in SF ranged from 0.06 to 0.21 Hz, with the largest variation in subjects 3 and 4. Pilot testing revealed that step variables could be measured to within the following RMS differences of a known criterion; 0.02 $m{\cdot}s^{-1}$ for velocity, 0.01 m for SL and 0.01 Hz for SF.

Positive work generated at the hip and ankle during stance varied greatly on an intra-subject basis in those athletes (1 and 4) that performed two trials of markedly differing velocities. An error analysis of joint work revealed intra-trial variability to be between three and eight times greater than differences arising from repeat digitisations of a single trial.

Table 2 Selected kinematic and kinetic results for each trial

Variable	Unit	Trial							
		1A	1B	2A	2B	3A	3B	4A	4B
Velocity	m/s	10.37	10.14	10.10	10.09	9.07	9.06	9.96	9.61
Step length	m	2.25	2.17	2.31	2.27	2.03	1.94	2.34	2.35
Step frequency	Hz	4.62	4.68	4.35	4.44	4.47	4.68	4.27	4.10
Peak-to-peak CM oscillation	m	0.057	0.047	0.052	0.054	0.062	0.054	0.058	0.057
Maximum vertical force	BW	4.39	4.37	3.93	3.79	4.35	4.09	3.68	3.62
Braking phase duration	s	0.039	0.041	0.043	0.044	0.054	0.049	0.043	0.047
Propulsive phase duration	s	0.058	0.055	0.063	0.061	0.058	0.054	0.062	0.063
Hip positive work after touchdown	W/kg	1.10	1.74	0.93	0.85	0.97	1.15	0.82	1.33
Ankle positive work before take-off	W/kg	1.09	0.69	0.87	1.01	1.02	0.95	1.15	0.64

DISCUSSION:

Of the four subjects in this study, two exhibited a significantly higher velocity in one of the two measured steps than the other. The two subjects that performed steps of different velocities generated less positive work at the hip in early stance and more positive work at the ankle in late stance in the quicker of the two trials. However, for the two subjects who performed two steps of similar velocities, the differences in joint work at the ankle and hip between the steps were much smaller in magnitude. On an intra-subject basis, there was a common trend present, which directly linked the amount of positive work generated at the ankle joint prior to take-off with the velocity of the step. The ankle is responsible for the transmission of power from the leg to the track during the final propulsive part of the support phase. It follows that when the plantar flexors were able to generate more positive work, the propulsion, and therefore velocity of the step, was increased.

The anatomy of the leg, with the larger more powerful muscles located around joints proximal to the ankle, means that the amount of positive work done by the plantar flexors is not solely self-initiated. The presence of two-joint muscles in the leg allows the distribution of power from the proximal muscles to those at the ankle joint (Jacobs & Ingen Schenau, 1992). It is clear therefore, that the magnitude of the positive work performed at the ankle is dependent upon actions further up the kinetic chain, and the achievement of a high value was most likely a result of the coordinated action of the whole limb.

The hip joint work in early stance and ankle joint work in late stance were the kinetic variables that appeared to be most important to sprint velocity. The timing during the contact phase of these two variables was consistent with the proximal-to-distal sequencing that has previously been shown to characterise sprint performance (Jacobs & Ingen Schenau, 1992). This sequencing has important implications for sprint coaches, both when designing conditioning programmes and undertaking technical work with sprinters.

The faster of the two trials for each of subjects 1 and 4 was completed with shorter braking phase duration, and hence minimal braking. Subject 3 showed a long braking duration in trial 3A, which may be linked to the relatively large maximum vertical force developed, and the subject's lesser ability compared to the rest of the group. This was overcome by a longer propulsive phase, which increased the SL in order to maintain velocity. Furthermore, analysis of each subject, revealed performance related variables that were specific to each athlete. Therefore, an analysis similar to that performed here on any well-trained sprinter is likely to reveal individual factors that relate to performance, which should aid the coach in the development of individualised technical training programmes.

CONCLUSION:

By adopting the approach outlined here it was possible to use changes in joint kinetics to help to explain intra-subject differences in velocity. Two kinetic variables that appeared to be linked to the velocity of the step were the positive work generated by the hip after touchdown and by the ankle prior to take-off. Consideration of these actions should be given when carrying out technical work with individual sprinters. However, the results gathered here were taken from four athletes performing two trials each, so further study would be necessary to confirm the importance of these variables across all well-trained sprinters.

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