LOWER LIMB JOINT KINETICS IN THE SPRINT START PUSH-OFF

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Previous studies have analysed lower limb joint kinetics during sprint performance, but not addressed the earliest contact out of the blocks. The aim of this study was to report lower limb joint moments and powers during the first stance phase of the sprint push-off. One competitive male sprinter performed 10 maximal sprint starts. An automatic motion analysis system (CODA, 200 Hz) with synchronised force plate data (1000 Hz) were used to collect kinematic profiles at the hip, knee and ankle and ground reaction forces for the first stance phase. Cluster markers defined the orientation of the lower limb segments in 3D. Knee and hip kinetics differed to the later phases of sprint, whereas similarities were found at the ankle. This study highlights the need for the push-off phase to be considered separately from both research and practical perspectives.

KEY WORDS: 3D inverse dynamics, joint moment, joint power

INTRODUCTION: Sprinting success relies on performance of a fast start followed by achievement and maintenance of the highest possible running velocity. Consequently, sprint performance has been separated into several distinct phases (Delecluse et al., 1995). A powerful start is essential to reach a high level of performance (Mero, 1988). Research has analysed joint kinetics during the block (Mero et al., 2006), second stance (Jacobs & van Ingen Schenau, 1992; Jacobs et al., 1996), acceleration (Johnson & Buckley, 2001), and maximal velocity phases (Bezodis et al., 2008; Kuitunen et al., 2002). This study concentrates on the first stance out of the blocks and extends the kinematic analysis reported by Coh et al., 2006. The aim of this study was to improve the understanding of lower limb joint kinetics during the first stance phase following the sprint start.

METHODS: Data Collection: An internationally competitive male sprint hurdler participated in the study (age 27 yrs, height 1.80 m, mass 74.4 kg, 110 m PB 13.48 s). Four cx1 CODA scanners (Charnwood Dynamics Ltd, UK) were located around a force plate (Kistler Instruments 9287BA, Switzerland) for data collection. Kinematic data (200 Hz) and synchronised ground reaction force data (GRF, 1000 Hz) were captured during the first stance phase out of the blocks. 31 active markers were placed on the subject including three rigid clusters (anterior-lateral aspect of the thigh; lateral aspects of the shank and foot) on the first contact limb. A hip marker was located on the greater trochanter of the same limb. The 4-marker clusters defined the orientation of the segments in 3D, while reducing error from soft tissue artefact (Schache *et al.,* 2008). Kinematic data collected during static trials, together with additional anatomical reference markers, were used to calibrate the athlete, before he completed 10 maximal sprint starts on a start signal. A successful trial was achieved when the athlete accelerated well beyond the measurement volume (>9 m), made first stance contact on the force plate and produced a start with no obvious deviation in technique.

Data Processing: All data were processed in Visual 3D™. Coordinate data were smoothed using a fourth-order Butterworth low-pass digital filter with a cut-off frequency of 8 Hz, determined by residual analysis (Winter, 2005). All outputs were normalised to 100% stance phase (i.e. when F_z >10N). GRF in the vertical (F_z) and horizontal (F_y) directions were normalised to body weight units (BW). Angles (θ) and angular velocities (ω), and joint moments (M) at the ankle (M_A), knee (M_K) and hip (M_H) for the first stance phase were calculated from kinematic data, GRF and anthropometric data using standard inverse. Anthropometric data were taken from de Leva et al. (1996), with the exception of the foot segment where the value of Winter (2005) was used. The mass of a typical sprinting shoe

(0.2 kg) was added to the mass of the foot segment (Hunter et al., 2004). Mechanical power (P) at the hip (P_H), knee (P_K) and ankle (P_A) were calculated as the respective products of M and ω. In accordance with the recommendations of Hof (1996), M and P were scaled to body weight and height. Due to the critical motions of sprint performance, analysis was focussed on lower limb flexion and extension, with the latter being positive for ω and M. Mean values (±sd) for the 10 trials have been reported for hip, knee and ankle during the first stance out of the blocks.

RESULTS & DISCUSSION: To facilitate comparison, all values from previous research have been scaled according to Hof (1996). The entirely plantar-flexor M_A (Figure 1) was similar in pattern and magnitude (0.30 ± 0.02) to previously reported data obtained from later in sprint runs; Stefanyshyn & Nigg (1998) and Bezodis et al. (2008) found peak normalised values of 0.21 – 0.24 and 0.25, respectively. However, the peak M_A is somewhat higher than during the second contact phase peak of approximately 0.17 (Jacobs & van Ingen Schenau, 1992). The current values are also similar to those reported by Farley and Morgenroth (1999) during maximum height hopping (0.33). This element, in addition to a similar movement pattern at the ankle, may support the use of ballistic hopping in sprint push-off training. According to the electromyographic (EMG) analysis of Jacobs and van Ingen Schenau (1992), the increase in M_A during the first half of stance resulted from increased triceps surae and decreased tibialis anterior force. The subsequent decrease in M_A was explained by a decreased moment arm and increased contraction velocities of the plantar-flexor muscles.

The eccentric action (peak P_A = -0.23 ± 0.05) of the plantar-flexors until around 50% of stance, followed by concentric action indicates that the ankle absorbed energy during the first half of stance and generated energy during the second half. The eccentric phase is necessary to control the collapse of the lower limb and prevent the limb moving across the ground too quickly. The concentric phase has been shown to result from transported P from proximal muscles and P liberated by the plantar-flexors (Jacobs et al., 1996). The elastic energy stored and released by the plantar-flexors contributes to the high peak in concentric P_A (0.88 ± 0.06). This may support the importance of P generation and the SSC of the plantar-flexors to the sprint push-off (Cavagna et al., 1968). Although revealing a similar eccentric-concentric pattern, the magnitude of P_A differed from those reported during the later sprint phases. There was a considerably lower proportion of eccentric contraction and the magnitude of the eccentric phase was relatively small in this study. For example, Bezodis et al. (2008) found eccentric and concentric peaks of -1.26 and 1.01, respectively. The differences underline the importance in considering the push-off and maximum velocity phases separately and may also confirm that the transfer of energy mechanism described by Jacobs et al. (1996) produces the relatively high peak concentric P_A during the first stance phase.

The main P_K phase was concentric (power generating) extensor action, which began around 15% and continued until 80% of stance. The increasing net extensor M_K (peak = 0.05 ± 0.01) may be due to increasing activity of the extensors or decreasing activity of the flexors. The initial flexor M_K (-0.04 ± 0.01) after touchdown has been shown to be caused by the contraction of the hamstrings (Jacobs & van Ingen Schenau, 1992). Despite the torque caused by this contraction, (Figure 1), the knee joint still extends thus creating eccentric knee flexion (peak = -0.10 ± 0.03).

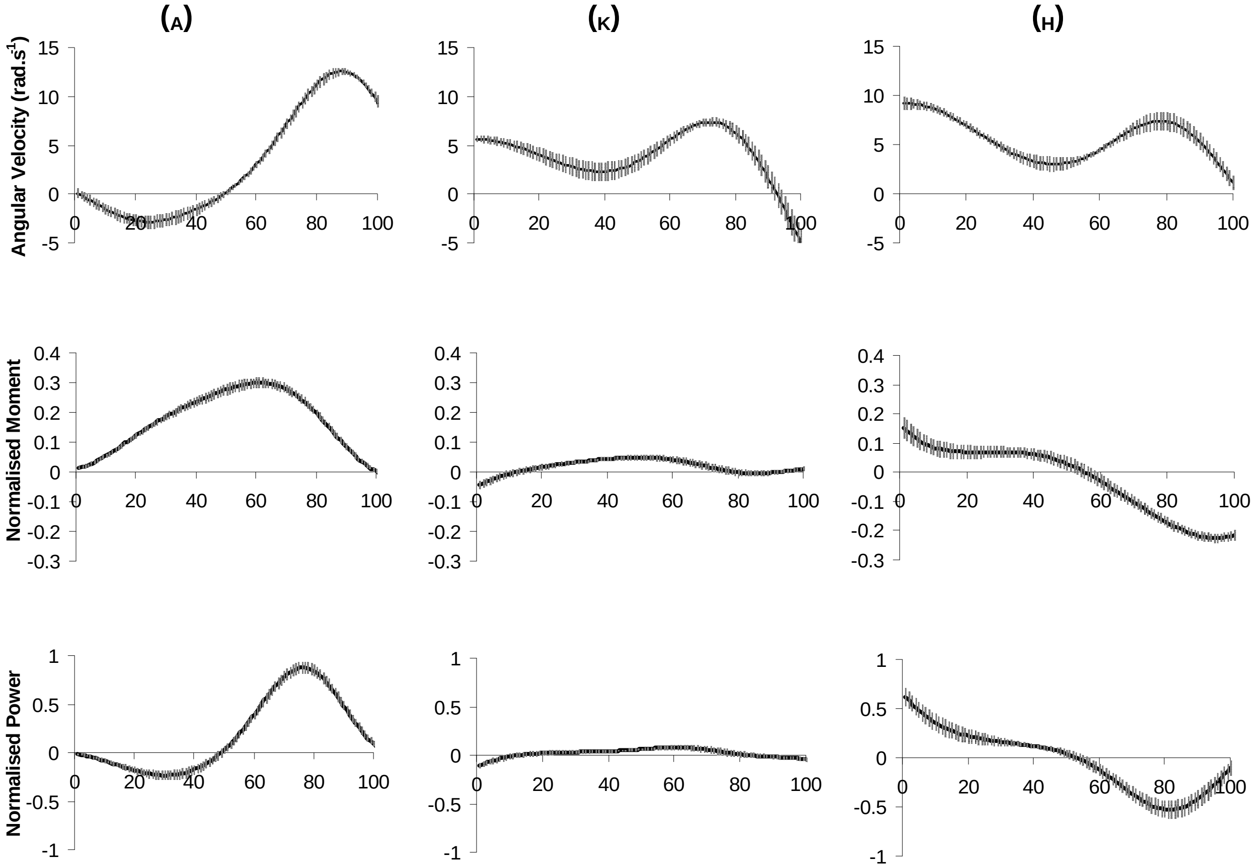

Figure 1: Angular velocity (*ω*), net joint moments (*M*) and powers (*P*) at the ankle ($_{\mathrm{A}}$), knee ($_{\mathrm{K}}$) and hip ($_{\mathrm{H}}$) for the first stance phase. Values are the mean for all trials and expressed as a percentage of stance. Vertical bars indicate ±1sd.

A co-contraction of knee flexors and extensors prevented an early increase in ω (ω decreased from touchdown to 40% of stance) and thus prevented the knee from fully extending too early in stance, as observed previously by Jacobs *et al.* (1996). An early leg extension would result in an increase in vertical velocity of the CM that would contradict the aim of the task, to increase horizontal velocity of the CM. This increase and subsequent decrease in extensor *M* results in a corresponding increase and decrease in ω at the knee. Knee kinetics were similar to those reported for the second stance phase (Jacobs & van Ingen Schenau, 1992) but differ from the irregular and undulating patterns reported during later phases of sprinting (Bezodis et al., 2008; Johnson & Buckley, 2001). These observations further support the need for separate analysis of the push-off phase.

Due to constant extension of the hip, the extensor M_H during the first half of stance (peak = 0.15 ± 0.03) results in a *P* generating concentric phase (peak = 0.62 ± 0.09) and the flexor M_H (peak = -0.23 ± 0.01) in the second half of stance results in a *P* absorbing eccentric phase (peak = -0.53 ± 0.09). M_H and P_H were similar in both pattern and magnitude between the present study and second stance phase findings (Jacobs & van Ingen Schenau, 1992; Jacobs et al., 1996) but differ compared to hip kinetics found in the later phases (Bezodis et al., 2008; Johnson & Buckley, 2001). During the acceleration phase Johnson & Buckley (2001) recognised the horizontal GRF acted in the posterior direction and thus a hip flexion *M* was required to prevent premature extension of the hip. Thus, since the hip continued to extend despite this *M*, an eccentric *P* was produced during the acceleration phase. In this study, due to F_y acting in the anterior direction for the majority of the sprint push-off, there was no flexor M_H early in stance. In the present study M_H and P_H are similar both in pattern and magnitude to those reported by Jacobs & van Ingen Schenau (1992) and may indicate the mechanisms explaining the hip movement during the second stance also control the first.

Although these similarities could be a characteristic of the push-off phase, they may be an attribute of the subject used in this study. Further analysis of other athletes is required to validate these observations.

CONCLUSION: Joint kinetics for the first stance out of the blocks in the sprint start were found to be similar to those previously reported for the second stance. Differences, particularly in knee and hip kinetics, were evident between the push-off and data reported for the later stages of sprint performance. This underlines the importance of considering the push-off as an individual phase of sprint performance, from both research and practical perspectives. The similarity between ankle kinetics in hopping and the sprint push-off supports the use of ballistic hopping techniques in sprint training. Cluster markers facilitate greater scope than the location of joint centre method used by previous sprint studies and will enhance future research.

REFERENCES:

Arampatzis, A., Bruggemann, G. & Metzler, V. (1999). The effect of speed on leg stiffness and joint kinetics in human running. *Journal of Biomechanics*, 32, 1349-1353.

Bezodis, I.N., Kerwin, D.G. & Salo, A.T. (2008), Lower-limb mechanics during the support phase of maximum-velocity sprint running. *Medicine and Science in Sports and Exercise*, 40, 707-715.

Cavagna, G.A., Dusman, B. & Margaria, R. (1968). Positive work done by a previously stretched muscle. Journal of Applied Physiology, 24, 21-34.

Coh, M., Tomazin, K. & Stuhec, S. (2006). The biomechanical model of the sprint start and block acceleration. *Physical Education and Sport,* 4, 103-114.

Delecluse, C.H., van Coppenolle, H., Willems, E., Diels, R., Goris, M., van Leemputte, M. & Vuylsteke, M. (1995). Analysis of 100 meter sprint performance as a multidimensional skill. *Journal of Human Movement Studies*, 28, 87-101.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics,* 29, 1223-1230.

Farley, C.T. & Morgenroth, D.C. (1999). Leg stiffness primarily depends on ankle stiffness during human hopping. *Journal of Biomechanics*, 32, 267-273.

Hof, A.L. (1996). Scaling gait data to body size. *Gait Posture,* 4, 222-223.

Jacobs, R., Bobbert, M.F. & Ingen Schenau, G.J.van. (1996). Mechanical output from individual muscles during explosive leg extensions: the role of biarticular muscles. *Journal of Biomechanics*, 29, 513-523.

Jacobs, R. & Ingen Schenau, G.J.van. (1992). Intermuscular coordination in a sprint push-off. *Journal of Biomechanics*, 25, 953-965

Johnson, M.D. & Buckley, J.G. (2001). Muscle power patterns in the midacceleration phase of sprinting. *Journal of Sports Science*, 19, 263–72.

Kuitunen, S., Komi, P.V. & Kyrolainen, H. (2002). Knee and ankle joint stiffness in sprint running. *Medicine and Science in Sports and Exercise,* 24, 483-489.

Mero, A. (1988). Force – time characteristics and running velocity of male sprinters during the acceleration phase of sprinting. Research Quarterly for Exercise and Sport, 59, 94 – 98.

Mero, A., Kuitunen, S., Harland, M., Kyrolainen, H. & Komi, P.V. (2006) Effects of muscle – tendon length on joint moment and power during sprint starts. *Journal of Sports Science,* 24, 165-173.

Stefanyshyn, D.J. & Nigg, B.M. (1998), Dynamic angular stiffness of the ankle joint during running and sprinting. *Journal of Applied Biomechanics*, 14, 292-299.

Winter, D.A. (2005), *Biomechanics and Motor Control of Human Movement*. New York: John Wiley and Sons, Inc.