SUPPORT LEG JOINT CONTRIBUTIONS TO CENTRE OF MASS ACCELERATION DURING THREE PHASES OF MAXIMAL SPRINTING

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The aim of this study was to investigate the contributions of the support leg joint moments and non-muscular forces to the horizontal and vertical acceleration of the centre of mass during three different steps in maximal sprinting. An induced acceleration analysis was performed to investigate these contributions during the third, ninth and 19th step. The horizontal and vertical contribution by the ankle joint moment increased from the third to the 19th step while the contribution by the MTP joint moment increased vertically and decreased horizontally from the third to the 19th step. The knee decelerated the centre of mass horizontally while providing vertical support in all three steps with a larger variability observed in steps three and nine. This type of analysis has the potential to quantify the effect of segment orientation on centre of mass acceleration.

KEY WORDS: Induced Acceleration Analysis, Joint kinetics, Force application

INTRODUCTION: Acceleration is essential to performance in the sprints. Research has shown that during sprint acceleration, elite sprinters are better able to direct the ground reaction force (GRF) more horizontally (Rabita et al., 2015). Joint moments have previously been reported for different steps across the initial acceleration, transition and maximal velocity phases in sprinting (e.g. Bezodis et al., 2014; Hunter et al., 2004; Bezodis et al., 2008). Generally, larger magnitudes were reported for the hip and ankle moments compared to the knee which possibly suggest an important role for hip and ankle during ground contact. However, the direct effect of joint moments and non-muscular forces (centripetal acceleration, gravity) on the acceleration of the centre of mass (CM) is still not well understood. Due to dynamic coupling of the multi articulated body, forces acting at one joint or segment can affect the acceleration of all body segments (Zajac, 2002). An induced acceleration analysis (IAA) allows the quantification of the contribution of a joint moment to the acceleration of each segment and whole body CM (Zajac, 2002). The aim of this study was to investigate how the contributions of the support leg joint moments, centripetal acceleration of the segments (CA) and gravity to the horizontal and vertical acceleration of the centre of mass differed between three different steps in maximal sprint acceleration.

METHODS: One well trained male sprinter (day 1: 74.6 kg, day 2: 73.9 kg, 1.78 m, 100 m PB: 10.45 s) gave written informed consent to participate after institutional ethical approval. The sprinter was injury free throughout testing. Two testing sessions (two weeks apart) were conducted on an indoor track. On the first day, the participant performed three maximal 10 m and three maximal 20 m accelerations while kinematic and kinetic data were collected from the third and ninth step respectively. On the second day the participant performed three maximal 40 m accelerations while data were collected from the 19th step. The starting line was placed 2 m, 12 m and 34 m, respectively, from two force plates (1000 Hz; Kistler type 9827CA, Kistler Instruments AG, Winterthur, Switzerland) positioned in series and operated by Codamotion analysis (Charnwood Dynamics Ltd, UK). One mini DV digital camera (Sony Z5) was set up 15 m from the centre of the running lane with a 5.00 x 3.75 m field of view. It recorded at full resolution (1440 x 1080) at 200 Hz for 3 s with an open iris and a shutter speed of 1/600 s. The video and force plate data were synchronised to the nearest 0.001 s using a series of illuminating LEDs (Wee Beastie, UK).
The videos were extracted using Dartfish Team Pro 6.0 (Dartfish), converted to .avi format and de-interlaced in VLC 2.1.3 (VideoLan, France). They were digitised in Matlab (The

MathWorks Inc., USA, version R2014a) using an 18 point model and reconstructed using a nine parameter 2D-DLT with lens correction. Kinematic data were filtered with a 4th order low pass Butterworth filter with a 26 Hz cut-off frequency. The body was modelled using five segments; forefoot, rear foot, shank, thigh and head, arms and trunk (HAT). Data from de Leva (1996) were used to calculate the inertia data for all the segments except the foot. For the foot segments, data used by Bezodis et al. (2014) was used with the mass of the sprint shoe added. Linear and angular segment velocities and accelerations were calculated using the gradient function in Matlab. Ground contact was identified using a 10 N threshold in vertical GRF. The GRF data were down sampled to 200 Hz and filtered with a 4th order low pass Butterworth filter with a 26 Hz cut-off frequency. Joint moments were calculated according to Winter (2005), working from the ground up. The forefoot segment and metatarsal phalangeal joint (MTP) were included in the calculation when the centre of pressure (COP) was in front of the MTP joint (Stefanyshyn & Nigg, 1997).

The contributions to CM acceleration were approximated using an IAA (Zajac, 2002). The dynamic equations of motion were written in matrix form $c=A*x$ (Hof & Otten, 2005) where A is a coefficient matrix of the equations of motion, c represents the inputs (joint moments, gravity, CA) and x represents the outputs (accelerations, intersegmental forces, GRF). The foot-floor contact was treated as a revolute joint located at the COP with one degree of freedom. The vector x was solved by inverting A to give $x = A^{-1}.c$. The contributions due to joint moments, gravity and CA were obtained by separately inputting the calculated joint moments, forces acting on the segments due to gravity and velocities of segment endpoint. The contributions to CM accelerations were obtained by dividing the calculated GRFs by the participants mass. The combined contribution by the ankle and MTP joint moments (Foot complex; FC) was also calculated. The total induced accelerations as well as the contributions from the individual inputs were averaged over each ground contact.

The accuracy of the analysis was evaluated by calculating the mean and standard deviation of the root-mean-square differences (RMSD) between the measured and calculated resultant CM acceleration relative to the measured peak resultant GRFs across all trials for each step.

RESULTS and DISCUSSION: The aim of this study was to investigate how the contributions of the support leg joint moments, CA of the segments and gravity to the horizontal and vertical acceleration of the CM differed between three different steps in maximal sprint acceleration. The accuracy of the model was deemed to be sufficient with relative differences between the measured and calculated resultant CM acceleration of 1.7 ± 0.3%, 1.7 ± 0.3% and 3.6 ± 0.7% for steps three, nine and 19 respectively. Figure 1 shows mean ± SD of the total and individual contributions by the hip, knee, ankle and MTP joint moments, foot complex (FC), centripetal accelerations (CA) and gravity to the CM acceleration during the three steps.

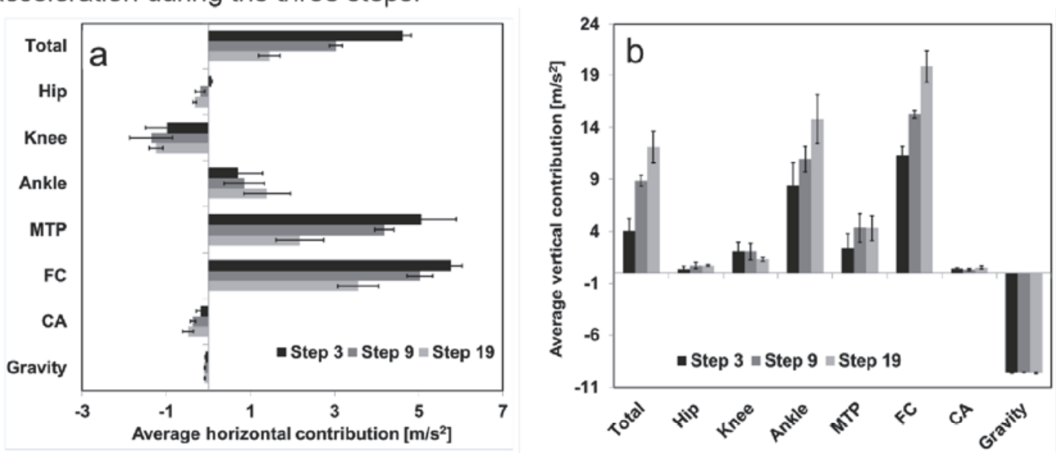

Figure 1: Mean ± SD of the total and individual contributions by the hip, knee, ankle and MTP joint moments, Foot complex (FC), centripetal acceleration (CA) and gravity to the horizontal (a) and vertical (b) induced CM accelerations during the steps three, nine and 19.

Overall, the MTP and ankle joint moments showed the largest contribution to horizontal (Figure 1a) and vertical (Figure 1b) CM acceleration. Previous research (Debaere et al., 2015; Koike & Nagai, 2015) attributed the largest horizontal and vertical contributions to the ankle joint moment. Debaere et al. (2015) and Koike & Nagai (2015) did not include on the MTP joint in their models despite the fact that moments about the MTP joint have been shown to be comparable in magnitude to those about the knee joint during sprint acceleration (Bezodis et al., 2014). The addition of the MTP joint in this model seems to have attributed a large portion of the horizontal CM acceleration to the MTP joint moment. This shift in contribution to more distal joints has previously been reported by Chen (2006) where it was suggested that this is less of a reflection on the joint moment's importance to CM acceleration but rather a quantitative description of their role to transmit forces onto the ground.

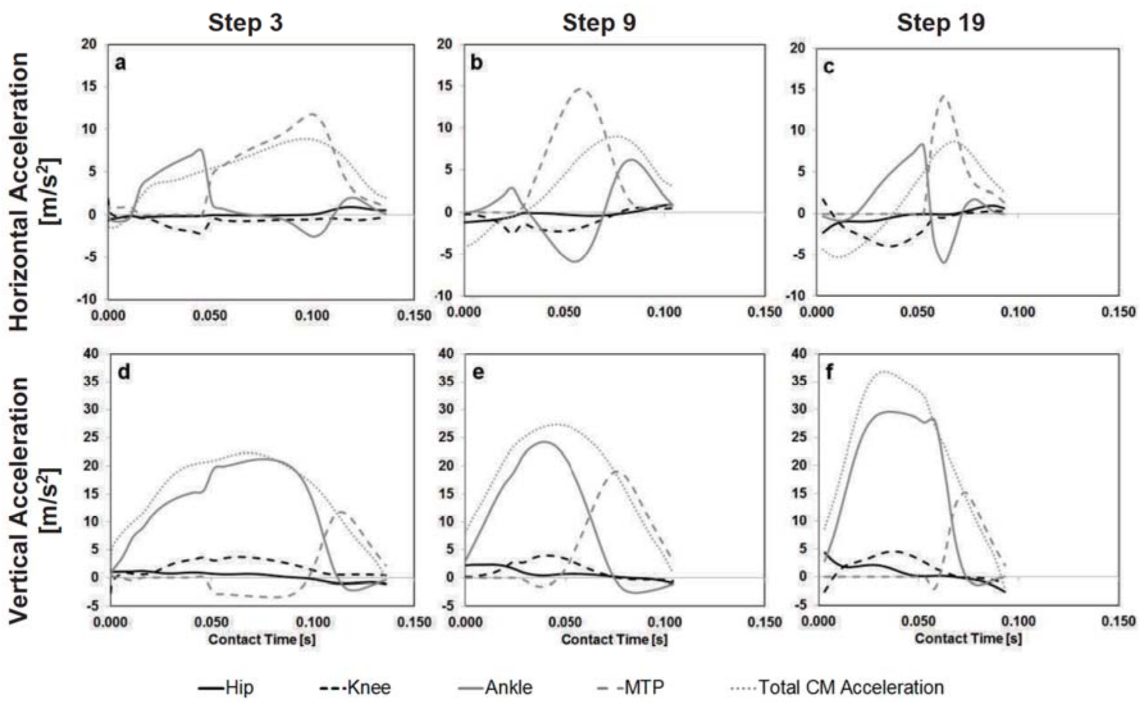

Figure 2: Contributions of the joint moments to the horizontal (a, b, c) and vertical (d, e, f) CM acceleration during the fastest trial of step three (a, d), nine (b, e) and 19 (c, f).

The contribution of the ankle moment to horizontal and vertical CM acceleration increased while the contribution by the MTP joint moment decreased horizontally and increased vertically from third to the 19th step. Since the MTP joint was only included in both the IDA and IAA calculations when the COP acted distally to the MTP joint and as this did not occur during the whole of stance, a switch between ankle and MTP joint contributions can be observed (Figure 2). Here, the ankle joint moment acted as the dominant contributor to horizontal CM acceleration while the MTP joint moment was negligible. The revolute joint with which the foot-ground joint was modelled allows rotation in the sagittal plane. As this motion is largely constrained by the ground, the next step in the analysis could involve a forefoot model restricting this rotation. When combining the ankle and MTP joint contributions, FC contribution increased vertically and decreased horizontally. The knee joint moment decelerated the sprinter's CM horizontally while providing vertical support during the majority of mid-stance during all three steps (Figures 1 & 2). During the third and ninth step the knee moment contribution had a larger variability than during the 19th step (figure 1). Interestingly, for these steps, the trials with the larger knee extension moments (data not shown) coincided with the trials where the knee moment caused the largest CM deceleration. This warrants further investigation with additional athletes. Also, the knee joint moment had a larger vertical contribution during the third and ninth step which could reflect its role of accelerating the CM upwards (Debaere et al., 2015) and therefore help to raise CM during these steps. The hip joint moment accelerated the CM horizontally during the third step and decelerated the CM during the ninth and 19th step. Although small, the centripetal accelerations decelerated the CM during all three steps with their magnitude increasing from the third to the 19th step. Finally, while these results provide an important first step in trying to further our understanding of the mechanics of maximal sprinting, the resulting induced accelerations and their changes across the three steps are determined by the magnitude of the moments and the orientation of the segments (Hof & Otten, 2005). IAA could provide insight into how sprinters use segmental orientations to maximise performance during sprint acceleration. This builds on previous work by Rabita et al. (2015), who found that faster sprinters are able to orientate their resultant GRF more horizontally while not necessarily producing a larger resultant force than average sprinters.

CONCLUSION: This study has quantified the contributions to the acceleration of the CM at the third, ninth and 19th step of a maximal sprint. The horizontal and vertical contribution by the ankle joint moment increased from the third to the 19th step while the contribution by the MTP joint moment increased vertically and decreased horizontally from the third to the 19th steps. The knee decelerated the CM horizontally while providing vertical support in all three steps with a larger variability observed during steps three and nine. This type of analysis has the potential to quantify the effect of segment orientation on centre of mass acceleration.

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