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HIP AND ANKLE JOINT MOMENT SYNERGIES DURING A SPRINT BLOCK START

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SUMMARY

The aim of this study was to investigate the joint moment synergies during a sprint block-start, using an Induced Acceleration Analysis. The results show that, in early stance, the hip and ankle joint moments act synergistically to propel and support the athlete's CM. Furthermore, the plantarflexor moment is crucial to the acceleration of the CM with its direct contribution to accelerate the CM as well as its role in stabilizing the ankle joint to provide a stable base for other joint moments to act on.

INTRODUCTION

The sprint start and the subsequent acceleration phase are crucial to success in a sprinting race. Several studies have reported that the best times in the 100 meters are achieved by athletes who generate the highest horizontal velocities when leaving the block [1]. Considering that the main purpose of the sprint start is to generate the greatest horizontal velocity in the shortest time interval, it is crucial, from a performance point of view, to understand how the athlete accelerates its centre of mass (CM).

The Induced Acceleration Analysis (IAA) is a method that allows the calculation of the CM acceleration portion that is generated by each joint moment, or in other words, the contribution of each joint moment to the overall acceleration of the CM [2].

With this is mind, the purpose of this study is to investigate how the lower limb joint moments contribute to the CM acceleration to better understand the joint moment synergies occurring during a sprint block start.

METHODS

After his warm-up routine, the participant, a male National Elite Sprinter (1.87m; 80Kg; 25yrs), performed a series of block starts. The motion and ground reaction forces of the first step, after leaving the blocks, were captured at a sampling frequency of 200Hz using an optoelectronic system of 8 infrared cameras (Qualisys Oqus 300 and Qualisys Track Manager, Qualisys AB, Gothenburg, Sweden), synchronized in time and space with a strain-gauge force plate (FP6090-15-2000, Bertec Corporation, Columbus, USA). The best trial was selected for analysis. A biomechanical model, composed by 7 rigid segments (HAT, bilateral thighs, shanks and feet) was built, and optimized through inverse kinematics using Visual 3D motion analysis software (Version 4.94.0, C-Motion, Inc, Rockville, USA).. The contribution of all joint moments and gravity to the horizontal and vertical acceleration of the participant's centre of mass was computed through an induced acceleration analysis [2]. For this analysis, the foot-floor contact was initially modeled as a hinge joint, which allowed the foot to rotate over its centre of pressure, about an axis aligned with the foot's medio-lateral axis (Free-foot model). The IAA was then repeated with a different contact model, in which the foot was fixed to the floor (Fixed-foot model).

RESULTS AND DISCUSSION

This analysis was limited to the stance phase of the first stride after leaving the blocks. The sagittal joint moment contributions from the support leg to the horizontal (a) and vertical (b) acceleration of the CM are presented in Figure 1. The contributions from the swing leg and gravity were not included in the results as they were negligible.

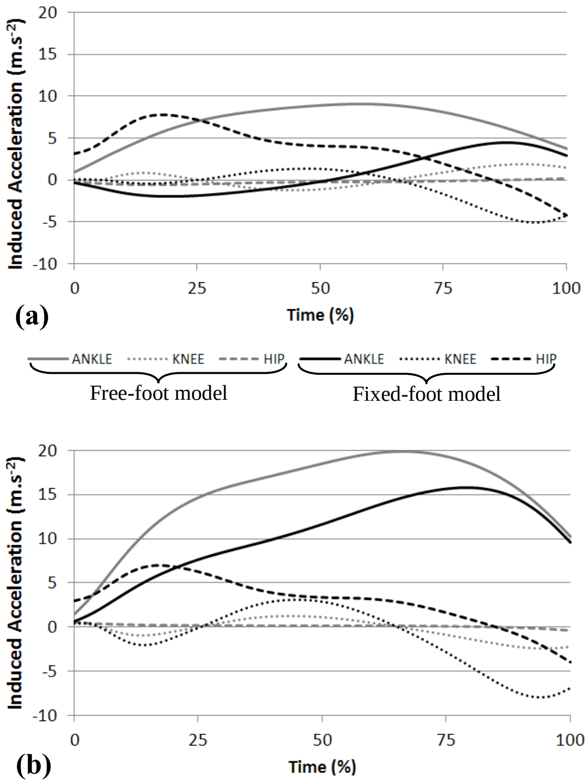

Figure 1: CM acceleration induced by the joint moments of the support leg. Grey – Free-foot model; Black – Fixed-foot model.

Initially, the IAA showed that the plantarflexors were the main contributors to both the horizontal and vertical CM acceleration. Additionally, as one can observe from the dashed grey line in Figure 1, the hip moment does not contribute to the CM acceleration. However, considering that the computed induced acceleration depends on both the magnitude of the joint moments as well as the configuration of the segments [2], these results are suspicious. Not only the GRF vector is distant from the hip joint centre (thus granting this joint an advantageous condition to accelerate the CM), but also the inverse dynamics show that, during the first 25% of the stance phase, the hip extensor moment is quite large and surpasses the plantarflexor moment (Fig. 2).

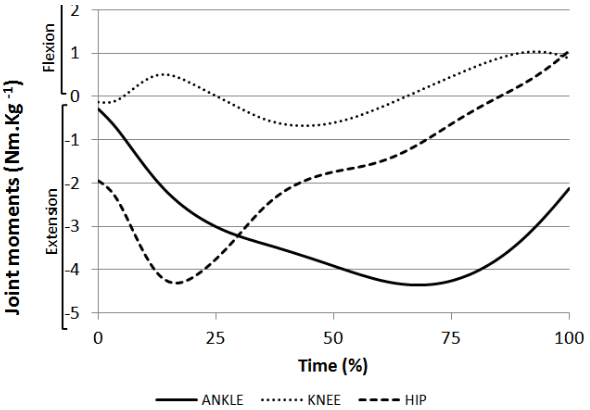

Figure 2: Sagittal joint moments of the support leg computed through inverse dynamics.

In an attempt to clarify this controversy, a very short visual simulation was run, in which the hip joint moment and the body configuration at that given frame were the only inputs. This simulation showed that, in isolation, the hip extensor moment acts to extend the hip and knee joints and consequently pushes the heel into the ground. However, from observation of the movement, this motion of the foot is not so pronounced during stance phase. In fact, for a very brief period in time during the first 25% of the stance phase, the foot is almost immobilized in relation to the floor.

In addition, the IAA results allow us to quantify the contribution of the support leg joint moments to the angular acceleration of the foot-floor joint (Fig. 3).

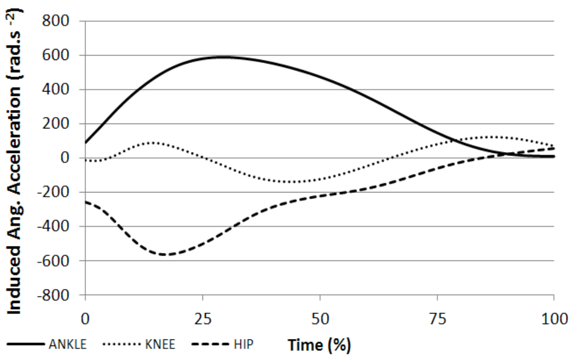

Figure 3: Angular acceleration of the foot-floor joint induced by the support leg joint moments.

As observed in Figure 3, this analysis confirms and further explains what the visual simulation showed: the hip extensor moment acts to accelerate the heel towards the ground, whereas the ankle plantarflexor moment induces an approximately equal and opposite acceleration, counterbalancing the hip's action at the foot. This suggests that the ankle plantaflexor moment may not only be acting to accelerate the CM, but also to stabilize the ankle joint, thus allowing other muscle groups, such as the hip extensors to accelerate the CM.

Assuming this is correct, a second IAA, with a different contact model, was performed to investigate how the same joint moments contribute to the CM acceleration when working with a stable ankle joint. In this IAA the foot was fixed to the floor, i.e. not able to rotate about its mediolateral axis as before. As observed in Figure 1 (black lines), this analysis showed that the hip extensor moment contribution to CM acceleration increases, and that during the first quarter of the stance phase its contribution to the vertical CM acceleration is higher than that from the plantarflexor moment. This change is even more drastic in the horizontal acceleration. It is crucial to highlight that the results from this second analysis only apply to the first quarter of stance phase, when the foot is relatively immobilized, and that for the remaining task duration the analysis should be performed with the free-foot model. Therefore, after the first quarter of the stance phase the hip moment contribution to accelerate the CM reduces, and the ankle plantarflexor becomes the main contributor to both the horizontal and vertical CM acceleration.

CONCLUSIONS

The results from this study suggest the existence of a synergy between the ankle and the hip joint moments, particularly during the early stance phase of a sprint block-start. Although a discrepancy seems to exist between the IAA results obtained with different contact models (free-foot and fixed-foot), these results are complementary. The combined results from these two analysis showed that the ankle plantarflexors play a major role propelling and supporting the CM by not only directly acting to accelerate the CM, but also by providing a stable ankle joint for other muscle groups, such as the hip extensors, to contribute to the CM acceleration.

ACKNOWLEDGEMENTS

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