MAXIMAL SPEED SPRINT RUNNING

T. Krosshaug¹, S. Linge¹
¹The Norwegian University of Sport and Physical Education, Oslo/Norway

Introduction

Even if many observations and findings have been reported on runners, inclusions of actual elite sprint runners in kinetic studies are few. Since results among “average performers” not necessarily apply to high-level athletes with special demands on sprinting abilities, more research seems justified on the latter group. Further, 3D modeling of the body seems to have become the norm in gait analysis (Eng et al. 1995), and also to some extent for low speed running (Novacheck 1998, McClay et al. 1999) but has not yet appeared for elite sprint running.

Bogert et al. (1996) stated that some degree of inconsistency seems to be present among various studies involving running. This seems to be the case on the reported hip joint moments in particular. At maximum sprinting speed, both the reported hip- and knee joint moments varies considerably in the literature. At the hip joint Mann (1981) and Simonsen et al. (1985) both found an initial extensor moment followed by a sudden change to flexor moment about 1/3 into the support phase. Ae et al. (1987), found no noteworthy work generated at the hip during the support phase. These results appear somewhat surprising, as the hip extensors by many are considered particularly important to generate drive in sprint running (Alexander, 1989, Delecluse, 1997). In the light of several studies of low-speed running (e.g. Simpson et al., 1990, Gordon et al., 1987, Derrick et al., 1998), this becomes even more peculiar, since hip extensor moments seems to be dominant throughout most of the support phase even in slow running. Simonsen et al. also found considerable EMG activity in the hip extensor muscles through most of the support phase, even though the calculated net moment was flexor dominated. Motivated by these previous inconsistencies, we performed a 3D inverse dynamics analysis on two male sprinters running at their maximal velocities. The following question was addressed: How does the anterior/posterior (AP) component of the ground reaction force (GRF) relate to the net joint kinetics of the support leg at maximum velocity?

Methods

Two male track-and-field athletes (S1 and S2), on an international level, volunteered to participate in the experiments. 24 reflective body markers were attached to each athlete, and recorded with a 240 Hz infrared cinematographical system (ProReflex, Qualisys Inc.) and 2 Amti force plates (960 Hz). The reconstruction of 3D position trajectories for the markers was provided by the Qtrac (Qualisys Inc.) software. Marker signal smoothing and interpolation were performed by the generalized cross validation package of Woltring (1986) in the cubic mode. The package was run in the true predicted mean-squared error mode, with supplied noise variance (2.2 - 2.7 mm standard deviation) as given by the output from the Qtrac calibration procedure. Derivatives were obtained through post-processing on the data output from the Woltring algorithm. An interpolating quintic spline was fitted to the data points, and first and second order derivatives could then be obtained from this higher order spline.

A standard 3D inverse dynamics model of the lower extremities was employed (Bresler et al., 1950). An optimization procedure involving singular value decomposition (Søderquist et al. 1993) was utilized to derive the segment embedded reference frame for the thigh. For the rest of the lower extremities, only three points were used for deriving the segment embedded frames. The static “calibration recording” of the athlete was performed to determine the anatomical axes of the 3D modeled segments, and the anatomical axes of the lower extremities were adjusted relative to the technical axes after estimation of the joint centers. The joint centers of the knee was determined by the methods of Davies et al. (1991). The ankle joint centre location was defined 1 cm distal to the lateral malleolus, as proposed by Eng et al. (1995). The hip joint centers were estimated by the method of Bell et al. (1990). Yeadon’s “stadium solid” method (Yeadon, 1990) was used for estimation of inertia parameters, however modified to allow
for a flexible ankle joint. The attitude angle convention of Woltring (1994) was used to estimate angles. The method of Woltring et al. (1994) was used to estimate angular velocity of the segments.

**Results & Discussion**

The subjects achieved 9.49 and 9.68 m/s respectively. At the initial part of the stance, a somewhat compliant support leg is required to cushion the impact (Derrick et al., 1998). For maximum velocity running, it seems that the major part of the shock absorption is done by the ankle plantar flexors. According to Stefanyshyn et al. (1998), the ankle joint generates two to three times as much energy as it absorbs. In contrast, the results in the current study did not support this statement since absorption was considerably larger than generation (Fig 2).

About 0.02 s into the support phase, a reduction of the AP braking force was seen (Fig 1, bottom row). Given the configuration of the body at that time, it is likely that the reduction of braking forces in this phase was caused by the simultaneous hip extensor and knee flexor moment. This indicates the importance of the hip extensors in sprint running, but also that the strength of the knee flexors is crucial so that an effective transfer of the momentum can occur (proximally to distally), and also prevent possibly dangerous hyperextension at the knee.

A sudden drop in hip extensor activity was seen for S1 prior to the maximum peak moment. The reason for this drop is unclear, however, it may be explained by the fact that the GRF cannot produce a net angular momentum of the body in a cycle of steady state running. A second possible explanation could be derived from the findings of Gruber et al. (1998) who suggests that rigid body models are debatable for high impact movements.

We observed that during the last phase of the driving phase, the hip extensors continued to generate positive power, which was followed by a relatively large power generation also in the ankle (Fig 1, mid-row). The knee moment was virtually non-existent during this phase, which at first might seem to be paradoxical considering dynamometer studies that showed high positive correlation between quadriceps strength and running speed (Alexander, 1989, Delecluse, 1997). This may, however, be explained by the co-contractions needed for power transfer from the hip, to the knee, and further to the ankle at the push off (e.g. Simonsen et al., 1985).

We observed that during the last phase of the driving phase, neither the thigh nor the shank pushed the rest of the body forward. Thus, the positive impulse that acted on the runner must have originated from the ankle and toes. For S1 we observed an amount (although small) of positive work done by knee extensors. These patterns of power generation and transfer of momentum are in keeping with the findings of previous studies concluding that there is a proximo-to-distal movement pattern of the support leg muscles in running (Jacobs 1993).

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**Figure 1:** The figure shows net joint moments (row 1), joint powers (row 2) and net joint forces (row 3). Extensor moments are positive. Positive net joint forces shown here are those applied onto a proximal segment.
The results produced by the present study do, in many ways, not seem to be in complete agreement with the previous maximum velocity studies, but a close match was found with several of the lower speed studies. The hip joint moment patterns during the support phase for S2 are in fact very comparable to the curves of Simpson et al., (1990), Gordon et al., (1987) and Derrick et al., (1998). This was the case also for S1, except for the large peak extensor moment about 0.02 s into the stance phase, and the subsequent fall in extensor moment. A positive generation of energy for the hip joint was obtained throughout most of the stance phase, which supports the theory that hip extensors are vital for sprint running.

Figure 2: Work generated and absorbed in 3 anatomical planes for the joints of the support leg. Positive work comprises the bar above the zero-line, and negative work below the line

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