CHANGES IN MOVEMENT CONTROL DURING ACCELERATION IN HUMAN SPRINTING

Koji Zushi¹, Takashi Mitsui¹ and Bruce Elliott²

¹ National Institute of Fitness and Sports in Kanoya, Japan  e-mail: zushi@nifs-k.ac.jp
² The School of Human Movement and Exercise Science, The University of Western Australia

INTRODUCTION

Reaching and then maintaining a high maximum velocity, which can only be achieved if a large acceleration phase is present, determine success in the 100m sprint. Therefore, coaches and athletes need to understand the changes to lower limb movement during the acceleration phase of sprinting.

Human sprinting is a bipedal movement, where at foot-strike the body rotates about the stationary axis of the foot on the ground. Jacobs et al. (1992) explained movement coordination at push off during sprinting by using a simple model represented as a heavy mass (centre of mass, CG) and a simplified leg (the line from CG to the point of foot contact). However, they only analyzed the first step from the start. This simple model was able to display realistic movement for a successful start and divided the horizontal velocity of the CG into two components; first the velocity derived from rotation of a simplified lower limb, and secondly the velocity produced by knee joint extension.

Sprinters lean forward immediately following the start and then lean backward with increasing velocity. Rotation of a simplified leg model must therefore be changed considerably during the acceleration phase of sprinting (Fig.1). On the other hand, a sprinter uses the work absorbed in the muscle-tendon complex of the stance for subsequent positive work to assist in forward acceleration (Asmussen et al., 1974., Cavagna, 1977., Komi, 1984.). Shortening and lengthening movements of a simplified leg must therefore also be changed during the process of acceleration (Figure 1). It is important to clarify the contribution of each segment of the simplified leg model (thigh, shank and foot) during rotational movements involved in the acceleration phase of sprinting. The purpose of this study was therefore to investigate the changes in the three segments of the leg at four points (5m, 15m, 30m, 45m) during the acceleration phase of a 60m sprint.

METHODS

Six male sprinters performed a 60m sprint with maximum acceleration. Mean ± SD of personal best record of the sample of sprinters was 10.71±0.17 s. All trials were filmed using five high-speed video cameras (250fps), which were positioned at the 5m, 15m, 30m and 45m marks from the start (one additional camera was used to capture the entire sprint (Figure 2).

Twenty-three landmarks were digitized for each subject using a motion analysis system and data were filtered with a net cut off frequency of 20Hz. The instantaneous velocities were recorded from a Rader Stalker Laveg Sport System, which was placed on a tripod behind the sprinter at the start.
The sprinting movement can be evaluated by using a simple model shown in Figures 3 and 4.

![Diagram](image)

The vertical and horizontal velocities of the CG are derived from two components, which are the result of rotation and the extension of the simplified leg. These data were calculated by geometrics related to changes of the rotation angle and the length of the leg (Figure 3, Jacobs et al., 1992). Relative velocity, which results from rotation of segments of thigh, shank and foot. Each velocities calculated by velocity differences between proximal and distal point of each segment (Figure 4).

**RESULTS AND DISCUSSION**

Mean velocity of a 100m sprint is simply the product of step frequency and length. However, the actual contribution of these two variables may be divergent with respect to velocity generation. First, we assessed the effect of stride length on increasing velocity during the process of acceleration in sprinting (Figure 5). The instantaneous velocities and stride lengths were increased but stride frequency was held constant over the measured distances.

The increases of stride length were achieved not during the contact phase but during the non-contact phase. Contact times were decreased and times in the air were increased. Stride length was affected by both horizontal and vertical velocities of the CG during the contact phase. Figure 6 shows the changes of both velocity components at the 5m, 15m, 30m and 45m marks. The horizontal velocity changed more at higher levels while maintaining a similar shape. On the other hand, vertical velocity remained similar for both level and shape. These results suggest that increased stride length was affected more by horizontal than vertical velocity.

Unfortunately this study did not measure the ground reaction forces because we were not able to set up four force platforms on the field at one time. However, it is clear that horizontal force is more important than vertical force in increasing stride length during the acceleration phase of sprinting.

Peter et al. (2000) concluded that runners achieved faster speeds not by repositioning their limbs more rapidly in the air but by applying greater forces to the ground. This finding supports the importance of stride length. But they showed that only vertical force was related to the increase in stride length in sprinting. Our results do not support this view. One reason for this may be the different experimental condition between the two studies. They had subjects sprint on a moving treadmill, whereas our subjects ran on the ground. The distal part of a simplified leg rotates around the CG in sprinting on a moving treadmill as compared with the proximal part of simplified leg rotating around the foot in sprinting on the stable ground, which is a more realistic movement.

![Graphs](image)
Figures 7 and 8 show the changes of sprinting forms and the rotational movement of the simplified leg at the 5m, 15m, 30m, 45m marks. The simplified leg at the instance of contact was angled forward to backward which changed with increasing velocity to approximately 100° at the 45m point. The acceleration was completed and velocity had reached a plateau at 45m. (Figures 5 and 6). The displacement of this angle increased in the breaking phase but was constant in the propulsion phase.

These results indicate that the changes of the sprinting form and the rotational movement of the simplified leg with increasing velocity may influence acceleration in sprinting.

Figure 7. Changes in sprint form and movement of simplified leg L with increase to acceleration during sprinting.

Figure 8. Changes in rotation movement of simplified leg L with increase to acceleration during sprinting.

Figure 9 shows the changes of the length of the simplified leg at the 5m, 15m, 30m, and 45m marks. The shortening of simplified leg was larger in the braking phase but was smaller in the propulsion phase with increasing velocity. It is possible that the simplified leg model stores elastic energy through the applied stretch and releases some of this energy as positive work (Komi 1984., McMahon et al. 1990.). Simplified leg models may therefore account for both rotation and spring functions of the lower limb in sprinting.

Velocity was then divided into rotation and shortening-lengthening components (Figure 10). The rotational influence on horizontal velocity was more closer to 45m. However, a similar shape was evident that rose rapidly until approximately 20% of the contact phase and later gradually declined over the contact period. On the other hand, the components of shortening-lengthening did not change in either level or shape. There was a rapid decline until approximately 30% of the contact phase followed by a gradual rise.

These results show that acceleration to increase horizontal velocity is affected not by the length component of the simplified leg but by rotation during the process of acceleration. These findings may indicate that the spring function in a simplified leg model does not act to increase horizontal velocity during acceleration in human sprinting. This supports the argument against the merits of spring like behaviour of the leg in human sprinting (Blickhan, 1989; Farley and Gonzales, 1996; He et al., 1991; McMahon et al., 1987).

The two component effects on vertical velocity did not change for either level or shape at the distances measured (Figure 10). The component of rotation affected vertical velocity negatively in almost all the contact phase over the 45m tested. The component of length showed positive values in almost all the contact phase. These results indicate that the two components of vertical velocity do not change with increasing velocity.

The simplified leg’s rotation results from rotations of thigh, shank and foot at the lower limb. Figure 11 shows the changes in horizontal and vertical velocities, which result from rotations of thigh, shank and foot segments at the distances of 5m, 15m, 30m and 45m.

The horizontal velocity of the three segments increased over 5m to 45m. This tendency was particularly evident for the shank compared with the thigh and foot. The velocity pattern of the shank showed the same tendency as the rotation component of the simplified leg model which rapidly rose over the first 20% of the contact phase and then gradually declined (Figure 11). On the other hand, the velocity of the thigh gradually rises until approximately 70% of the contact.
The velocity of foot remains relatively steady over the first 40% of the contact phase and then rapidly increases. These results indicate that the rotation of the shank strongly acts to increase the simplified leg’s rotation in almost all the contact phase and the rotation of thigh and foot act in the latter contact phase (Figures 11 and 12).

The vertical velocity of the three segments did not change for either level or shape over the distances measured. The vertical velocity of the shank was negative for almost all the contact phase. This means that the rotation of the shank generates horizontal not vertical velocity. On the other hand, the vertical velocity of thigh was positive for the first half of the contact phase and then became negative. The vertical velocity of foot was positive from 40% to 80% of the contact phase (Figure 11).

The results of this study lead to the following conclusions with reference to acceleration in human sprinting. A sprinter attains a maximum velocity following the start by altering stride length more than frequency. This increase is affected by an increase in horizontal velocity. An increase in horizontal velocity is affected more by rotational velocity than by an increase in length. The shank plays the major role in this velocity increase.

REFERENCES