# EFFECTS OF FATIGUE ON THE GROUND REACTION FORCES AND LEG KINEMATICS IN ALL-OUT 600 METERS RUNNING

**Hirosuke Kadono[1] Michiyoshi Ae[2] Yuta Suzuki[1] and Kazuhito Shibayama[1]**

**Doctoral Program in Physical Education Health and Sports Sciences, University of Tsukuba, Tsukuba, Japan[1]**
**Institute of Health and Sports Science, University of Tsukuba, Tsukuba, Japan[2]**

The purpose of this study was to investigate effects of fatigue on the ground reaction forces and leg kinematics during all-out 600m running, which was performed by eight male middle-distance runners. Their running motion was videotaped (300Hz) and the ground reaction forces were measured (500Hz) at the 150m and 550m marks of the 600m running. From the 150m to 550m mark, running speed significantly decreased ($p<0.001$) while the 2nd half of the support time significantly increased ($p<0.01$). During the 2nd half of the support phase, the horizontal impulse ($p<0.05$) and the average force ($p<0.001$) of the ground reaction force significantly decreased. Furthermore the average angular velocity of the support shank significantly correlated with the horizontal average force ($r=-0.811$, $p<0.001$), the ratio between the vertical and horizontal average force ($r=0.803$, $p<0.001$). Therefore it is likely to be one of the important techniques to maintain large forward lean and angular velocity of the support shank during the support phase in the final stage of the middle-distance running races.

**KEY WORDS:** support time, horizontal force, shank

**INTRODUCTION:** In the 400m sprint and 800m middle-distance running, which the running times are lesser than two minutes, the peak running velocity is achieved in the initial stage of the race, and the running velocity progressively decreases toward the end of the race (Gajer et al., 2007; Abbiss & Laursen, 2008). To achieve a high performance in these events, runners have to reach a large running velocity as quickly as possible and to maintain it as long as possible There are some studies on effects of fatigue on kinematics and kinetics for the sprint running (Chapman, 1982; Sprague & Mann, 1983; Nummela et al., 1996). But there is less information of the changes in kinematics and kinetics, especially the ground reaction forces (GRF) due to fatigue during the middle-distance running. In official 800m races, the final 200m is likely to be spent to decide a winner of the race with different running kinematics of stride frequency in defiance of fatigue witch accumulates in the preceding 600m. Therefore, we assumed that the 600m running with a full effort would be suitable to asses the effects of fatigue on the GRF during a large portion of the 800m race without unnecessary suffering runners. The purpose of this study was to investigate effects of fatigue on GRF and leg kinematics during an all-out 600m running, which was simulated the middle-distance race.

**METHODS: Data Collection:** Eight male middle-distance runners (height 1.76 ± 0.06m, body mass 64.3 ± 5.5 kg and 800m personal best record 1 min 49 s 77 ± 1 s 49) participated in this study. Subjects were asked to perform an all-out 600m running with a positive pacing strategy (Abbiss & Laursen, 2008) that the running speed at the initial stage of the race was larger. A pace maker's bicycling ahead of the subject was provided to keep a previously determined velocity. The subjects were videotaped (60 Hz) to determine the average running speeds at every 50 m intervals. The subject's running motion was videotaped (300 Hz) over one full running cycle and GRF were measured (500 Hz) at the marks of 150m and 550m of the 600m running.

**Data Analysis:** Twenty-three body landmarks were digitized at 150 Hz and reconstructed in real coordinate data. The real coordinates were smoothed by a Butterworth digital filter at cut off frequencies ranging from 6.0 to 7.5 Hz, which were decided by a residual method. The angle and angular velocity of the support leg segments, foot, shank and thigh were calculated from the smoothed coordinate's data. The running motion was divided into support and non support phases. The support phase was defined as the phase from the foot contact to the toe-off, and the non support phase was at the toe-off to next the foot contact. The support phase was further divided into 1st and 2nd half based on the instant of zero crossing of the anterior-posterior GRF. The impulses of the 1st and 2nd halves of the support phase were calculated by integration of GRF, the average forces were calculated by dividing the impulses by the support times, and a ratio of average vertical force to horizontal force calculated by dividing the average vertical force by the average horizontal one. The paired t-test was used to assess the significant differences between variables for the 150m and 550m mark. Pearson's correlation coefficient was calculated to examine the relationships between variables. The level of significance was set at $p<0.05$.

**RESULTS:** The average time of 600m running was 1 min 21 s 13 ± 1 s 61. Figure 1 shows that the averaged and individual patterns of the running speed change. The running speed increased after the start, rose to the peak at 50-100m interval, and gradually decreased toward the finish. Table 1 shows the running velocity, stride length and step time at the 150m and 550m marks. Running velocity at the 150m mark was significantly higher than the 550m mark ($p<0.001$). Stride length ($p<0.001$), support distance ($p<0.05$) and non support distance ($p<0.01$) at the 150m mark were significantly larger than the 550m mark. Step time, 1st half and 2nd half of support time at the 150m mark was significantly shorter than the 550m mark ($p<0.01$). Figure 2 shows the impulses and average forces of GRF. The vertical impulse in the 2nd half of the support phase at the 550m mark was significantly larger than the 150m mark ($p<0.05$), but the average force of the 2nd half of the support phase at the 150m mark was significantly larger than the 550m mark ($p<0.05$). In the horizontal component, the average force of the 1st half of the support phase at the 150m mark was significantly larger than the 550m mark. In the 2nd half of the support phase, the impulse and the average force in the 150m mark were significantly larger than the 550m mark. Figure 3 shows changes in the thigh and shank angles of the support leg, which were normalized by the support time and averaged. The shank angle was significantly smaller in 150m than 550m marks from

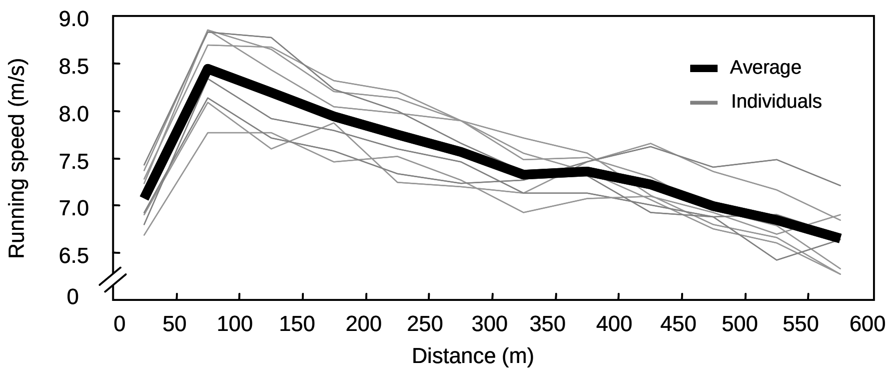


Figure 1 The averaged and individual patterns of running speed in the all-out 600m running.

Table 1 The running speed, stride length and stride frequency at the 150m and 550m mark of all-out 600m running.

| | | | 150m | | 550m | | Difference |
|---|---|---|---|---|---|---|---|
| Running velocity | | (m/s) | 8.22 | (0.43) | 6.77 | (0.33) | p<0.001 |
| Stride length | | (m) | 2.17 | (0.08) | 1.97 | (0.09) | p<0.001 |
| Support distance | | (m) | 1.01 | (0.06) | 0.96 | (0.04) | p<0.05 |
| Non support distance | | (m) | 1.16 | (0.08) | 1.01 | (0.09) | p<0.01 |
| Step time | | (s) | 0.265 | (0.014) | 0.292 | (0.017) | p<0.01 |
| Support time | 1st half | (s) | 0.062 | (0.003) | 0.071 | (0.006) | p<0.01 |
| | 2nd half | (s) | 0.064 | (0.006) | 0.074 | (0.005) | p<0.01 |
| Non support time | | (s) | 0.139 | (0.011) | 0.147 | (0.012) | ns |

Figures in parentheses are standard deviations.

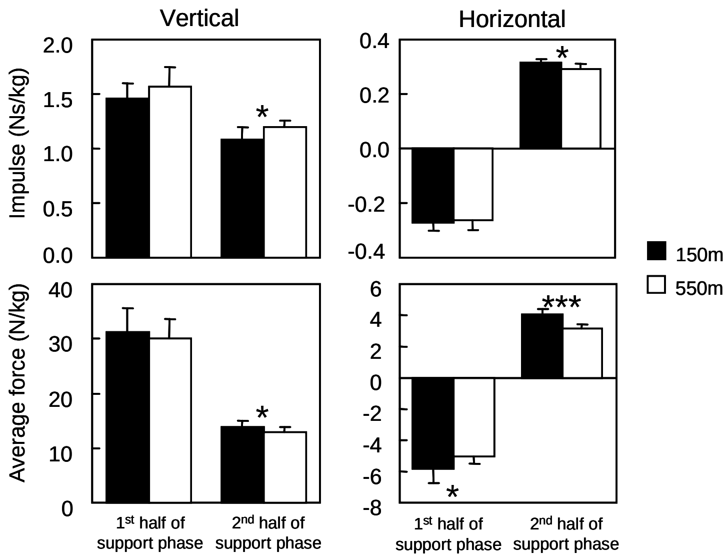


Figure 2 The Impulse and average force of GRF.
*, ** and *** represents a significant difference between 150m and 550m mark, p<0.05, p<0.01 and p<0.001.

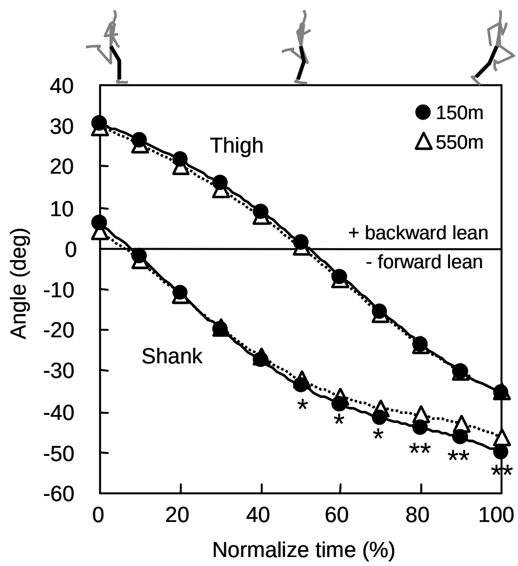


Figure 3 The thigh and shank angles of the support leg.
* and ** represent a significant difference between 150m and 550m mark, p<0.05 and p<0.01.

50% to 100% normalized time. During the 2nd half of the support phase, there were significantly relationships between the average angular velocity of the support shank and the horizontal average force ($F_h$, Figure 4, r=-0.811, p<0.001), and the ratio of the vertical average force ($F_v$) to the horizontal one ($F_h$), ($F_v/F_h$, Figure 5, r=0.803, p<0.001).

**DISCUSSION:** The 2nd half support time was significantly increased (p<0.01) while the running speed decreased (p<0.001) from the 150m to 550m mark. This change was similar to the results of the 400m sprint (Chapman, 1982; Sprague & Mann, 1983; Nummela et al., 1996). The average forces at the 550m mark were smaller than the 150m mark (Figure 2). This indicated that the subjects were unable to exert the large force during the support phase of the final stage of the race. Although the horizontal impulse and average force during the 1st half of the support phase decreased from the 150m to 550m mark, those also decreased during the 2nd half of the support phase. This indicates that the decrease in the running speed in the final

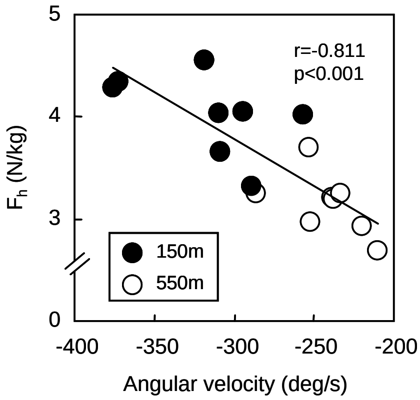


Figure4 Relationships between the average angular velocity of the support shank and the horizontal average force ($F_h$) during the 2nd half of the support phase.

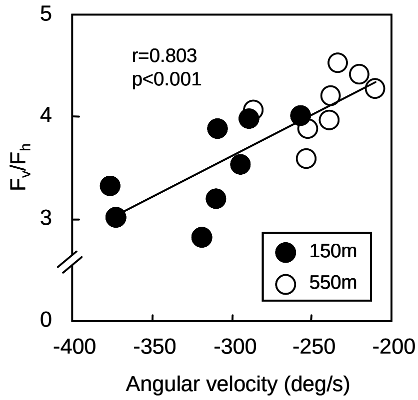


Figure5 Relationships between the average angular velocity of the support shank and the ratio between the vertical and horizontal average force ($F_v/F_h$) during the 2nd half of support phase.

stage was caused by the decreased acceleration force rather than the increased deceleration force of the GRF and implies that the motion in the 2nd half of the support phase should be investigated to see effects of fatigue. Kadono et al. (2008) indicated that in the positive 800m races, the average shank angular velocity of the support leg during the 2nd half of the support phase decreased with the decrease in running speed. Accordingly, in the present study, during the 2nd half of the support phase, the shank at the 150m mark was leaned more forward than the 550m mark (Figure 3). From these and the correlation results (Figure 4, 5), it may be thought that the subjects who rotated the shank forward in a lower angular velocity could not direct the GRF more horizontally. Therefore, maintaining large forward lean and higher angular velocity of the support shank in the 2nd half of the support phase is likely to be an important technique during the final stage of the 800m middle-distance running races.

**CONCLUSION:** It was concluded that the decrease in the running speed in the 800m race was caused by the decreased acceleration component rather than the increased braking component, and that the forward lean of the support shank in the final stage of the 800m race become smaller and slower than the initial stage of the race. Therefore it is likely to be one of the important techniques to maintain large forward lean and fast angular velocity of the support shank during the support phase in the final stage of the 800m middle-distance running.

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