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EFFECTS OF FATIGUE ON THE LEG KINETICS IN ALL-OUT 600M RUNNING

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The purpose of this study was to study effects of fatigue on ground reaction forces (GRF) and leg kinematics in all-out 600m running (simulating a positive pacing strategy of the 800m race). Eight male middle-distance runners were asked to perform an all-out 600m run and a non-fatigued 80m run with the same velocity as at the 550m mark of the all-out 600m run. Runs were videotaped (300Hz) in 2D and the ground reaction forces were measured (500Hz) at the 150m and 550m marks of the 600m run and the 50m mark of the 80m run. Step length, GRF, ankle plantar flexion torque and knee extension torque of the support leg decreased due to fatigue. Results suggest that in the final stage of a 800m race, the runner should not try to increase step length by applying great force to the ground, but should shorten the aerial phase and step time by faster recovery phase.

KEY WORDS: paced running, ground reaction force, joint torque, torque power

INTRODUCTION: To attain high performance in the 800m middle-distance running, a runner has to reach high running speed as quickly as possible after the start and maintain it as long as possible, resisting fatigue. This type of pacing is called a positive pacing strategy. According to the previous studies, many of world records of the 800m race and personal best records are likely to be attained with the positive pacing strategy (Tucker et al., 2006). In other words, the positive pacing strategy is essential for high performance in the 800m middle-distance race. There are several studies on the characteristics of kinematics for the elite middle-distance runners during official races (Skof & Stuhec, 2004; Leskinen et al., 2009). These studies described that the characteristics of kinematics for the elite middle-distance runners during official races, and suggested some effective running kinematics of elite runners. However, they have not referred to effects of fatigue on changes in kinematics and kinetics of the running motion. Although we can analyze running motion of elite athletes in official races, it is difficult to measure the ground reaction force (GRF) with the force platform technique in the races. For the middle-distance running, there are no studies on kinetics of the support leg even in the simulated race. The purpose of this study was to investigate effects of fatigue on the GRF and leg kinetics in all-out 600m running which simulated a positive pacing strategy of the 800m middle-distance race.

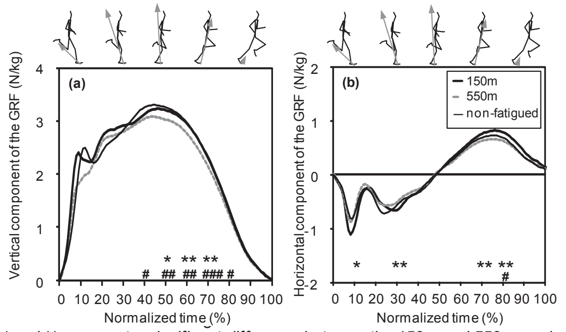
METHODS: Eight male middle-distance runners (height, 1.76$\pm$0.06 m; body mass, 64.3$\pm$5.5 kg; 800m personal best record, 1 min 49 s 77 ms $\pm$1 s 49 ms) participated in this study. The subjects were asked to perform two kinds of running, i.e. an all-out 600m run and a non-fatigued 80m run. The first running was a simulated an all-out 600m run with the positive pacing strategy (Abbiss & Laursen, 2008) in that the running speed was fastest where the initial stage of the 600m run, i.e. 200m, and gradually decreased toward the end of the run. The subject's running motion was videotaped with a high-speed movie digital camera operating at 300Hz from the lateral side of the subject at least one full running cycle, i.e. two steps. The GRF were recorded at a sampling rate of 500 Hz with three force platforms embedded in a row in the running track, which located at the mark equivalent to 150m and 550m from the start. The second trial as a non-fatigued run was a 80m run with the same velocity at the 550m mark of the previous all-out 600m run. The subjects started at a mark 50m apart from the force platforms to enter the videotaping area with a constant velocity and their natural running motion. The subject's running motion and the GRF were recorded with the same procedure as that of the all-out 600m run. Twenty-three body landmarks were digitized at 150 Hz, and two dimensional real-scaled coordinates data of the landmarks were reconstructed. The coordinates data were smoothed by a Butterworth digital filter at cutoff frequencies ranging from 6.0 to 7.5 Hz, which were decided by a residual method of Wells and Winter (1980). A two-dimentional 14-segments model was used to calcurate the location of center of mass and inertia properties of each segment were estimated, and linear and angular kinematics of the joints and segments were calculated. The running motion was divided into the support and airborne phases. The support phase was defined as a period from the instant of foot contact with the ground to the toe-off, and the airborne phase was from the instant of toe-off to the next foot contact. The support phase was further divided into the 1st and 2nd halves based on the instant of zero crossing of the anterior-posterior GRFs. The joint torques at the ankle, knee and hip joints were calculated by an inverse dynamics method and the joint torque power of the leg joints was calculated as a product of the joint torque and joint angular velocity. The GRF, joint torque, joint angular velocity and joint torque power of all subjects were normalized by the time of the support phase as 0% to 100% and the airborne phase as 100% to 200% respectively, and then averaged. The dependent t-test was used to test significant differences in variables between the 150m and 550m marks and between the fatigued and non-fatigued conditions. The level of significance was set at $p<0.05$.

RESULTS AND DISCUSSIONS: The average time of the 600m run was 1 min 21 s 13 ms ± 1 s 61 ms. Table 1 shows the running speed, step length and step time at the 150m and 550m marks and those of the non-fatigued condition. The running speed at the 550m mark was significantly lower than that of the 150m mark ($p<0.001$). The step length at the 550m mark was significantly shorter than those of the 150m mark ($p<0.001$) and the non-fatigued condition ($p<0.05$). Therefore, fatigue shortened step length at the 550m mark. The step time and support time at the 550m mark was significantly longer than those of the 150m mark ($p<0.01$), but it tended to be shorter than the non-fatigued condition.
Although the previous studies on sprint running (Sprague & Mann, 1983; Nummela et al., 1996) reported that the 2nd half support time increased due to fatigue in the 400m sprint, these studies compared their variables between the initial stage and final stage of 400m run, where the running speeds were significantly different. The change in the running speed from the 150m to 550m mark can be influenced by both the running speed and fatigue. To identify true effects of fatigue on the running motion, it is necessary to compare performance descriptors, ground reaction forces and kinetics not only between the 150m and 550m marks but also between the 550m mark and the non-fatigued condition. The results of the present study indicated that the step length decreased due to fatigue and that the longer step time could be caused by the decreased running speed rather than fatigue.
Figure 1 shows the averaged vertical (a) and horizontal (b) components of the GRFs at the 150m and 550m marks and non-fatigued condition. The vertical force at the 550m mark was significantly smaller at 50, 60 and 70% support time than those of the 150m mark, and 40% to 80% support time than those of the non-fatigued condition. The horizontal force at the 550m mark was significantly smaller at 10%, 30% and from 70% to 80% support time than those of the 150m mark, and 80% support time than those of the non-fatigued condition. These results indicate that the subjects were unable to exert the large force during 40% to 80% support phase due to fatigue.

Table 1
The running speed, step length and step time at the 150m and 550m mark of the all-out 600m running and in the non-fatigued condition

			150m		550m		non-fatigued		Difference	
									150m - 550m	550m - non-fatigued
Running speed		(m/s)	8.22	(0.43)	6.77	(0.33)	6.82	(0.33)	p<0.001	n.s.
Stride length		(m)	2.17	(0.08)	1.97	(0.09)	2.04	(0.07)	p<0.001	p<0.05
Support distance		(m)	1.01	(0.06)	0.96	(0.04)	0.96	(0.04)	p<0.05	n.s.
Airborne distance		(m)	1.16	(0.08)	1.01	(0.09)	1.08	(0.08)	p<0.01	n.s.
Step time		(s)	0.265	(0.014)	0.292	(0.017)	0.299	(0.011)	p<0.01	n.s.
Support time	1st half	(s)	0.062	(0.003)	0.052	(0.005)	0.053	(0.004)	p<0.01	n.s.
	2nd half	(s)	0.064	(0.006)	0.093	(0.007)	0.090	(0.007)	p<0.01	n.s.
Airborne time		(s)	0.139	(0.011)	0.147	(0.012)	0.155	(0.008)	n.s.	n.s.

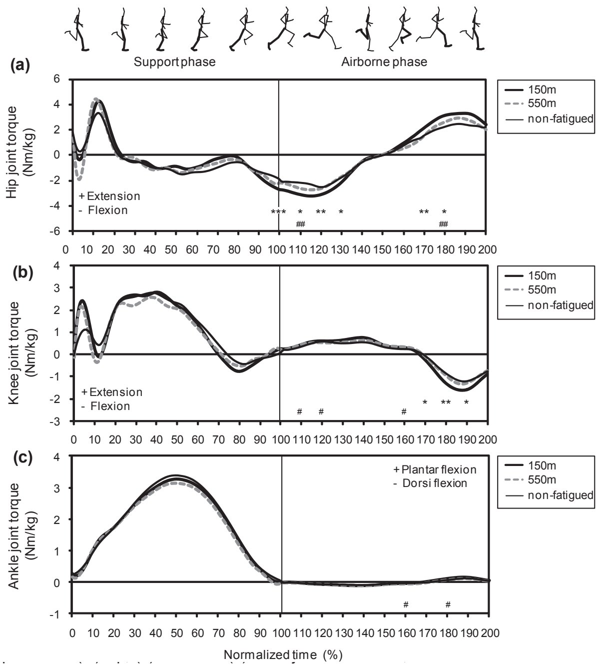
Figures in parentheses are standard deviations.



* and ** represent a significant difference between the 150m and 550m mark, p<0.05 and p<0.01. #, ## and ### represent a significant difference between the 550m mark and non-fatigued condition, p<0.05, p<0.01 and p<0.001.

Figure 1: The averaged the vertical and horizontal components of the GRF at 150m, 550m mark and the non-fatigued condition.

Figure 2 shows the averaged joint torque of the hip (a), knee (b) and ankle (c) joints during the support (0 to 100% normalized time) and the airborne phase (100 to 200% normalized time) at the 150m and 550m marks and non-fatigued condition. The knee extension torque at the 550m mark tended to be smaller from 20% to 50% time than the 150m mark and the non-fatigued condition, and the ankle plantar flexion torque at the 550m mark tended to be smaller from 30% to 90% time than the 150m mark and the non-fatigued condition.



*, ** and *** represent a significant difference between the 150m and 550m mark, p<0.05, p<0.01 and p<0.001.
#, ## and ### represent a significant difference between the 550m mark and non-fatigued condition, p<0.05, p<0.01 and p<0.001.

Figure 2: The averaged joint torque for the (a) hip, (b) knee and (c) ankle joint at the 150m, 550m mark and the non-fatigued condition.

In the 100m sprint, Endo et al. (2008) reported that the ankle planter flexion torque and its power significantly decreased, and the knee extension torque tended to decrease in the deceleration phase, the 85m mark than those of the 50m mark. The results of Endo et al.

(2008) and present study indicate that the ankle planter flexion torque and knee extension torque decreased due to the effects of fatigue of the ankle planter flexors and knee extensors in the deceleration phase of the sprint and middle-distance running. Therefore, the subjects were not able to exert a large GRF due to fatigue of the ankle plantar flexors and the knee extensors in the middle stage of the support phase at the 550m mark.
The hip flexion torque at the 550m mark was significantly smaller at 100% and from 110% to 130% time than the 150m mark, but it was significantly larger at 110% time than the non-fatigued condition. The hip flexion torque in the latter half of the support phase plays a role to decrease the thigh angular velocity and prepare for the airborne phase (Belli et al., 2002; Hunter et al., 2004). This result shows that the subjects tried to prevent from excessive rotation of the thigh and prepare for the recover of the leg prior to the airborne phase even in the fatigued condition. The hip extension torque at 550m mark was significantly smaller at from 170% to 180% time than the 150m mark, but it was significantly larger at 180% time than the non-fatigued condition.
The knee flexion torque at the 550m mark was significantly smaller from 170% to 190% time than the 150m mark, but tended to be larger from 180% to 190% time than the non-fatigued condition. The airborne time at the 550m mark was longer than tha 150m mark but it was shorter than the non-fatigued condition (Table 1). Therefore, the decreased hip and knee joint torque of the recovery leg and the longer step time from the 150m to 550m mark are likely to be due to the difference in the running speed between two marks rather than fatigue. It can be inferred from these results that the subjects would shorten the airborne time to increase or maintain the step frequency and the running velocity by flexing and extending the hip joint of the recovery leg more quickly than the non-fatigued condition.

CONCLUSION: The step length, the ground reaction forces, the ankle planter flexion torque and the knee extension torque of the support leg decreased due to fatigue. The results and discussion in the present study suggest that in the fatigued stage of the 800m race, the runner should not try to extend the step length by applying great force to the ground with the support leg, but should shorten the airborne time and step time by moving the recovery leg quickly.

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