

【Short Communication】

EFFECTS OF KNEE EXTENSOR MUSCLE GROUP FATIGUE ON LOWER LIMB JOINTS TORQUES DURING JUMPING

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I. Objective

Muscle fatigue reduces sport performance, and fatigue tolerance is thought to be affected by muscle endurance. Ogata et al.¹⁾ reported that speed reduction during 400 m racing, which has a significant correlation to the 400 m goal time, is affected by endurance of hip extension and flexion movements. This suggests that muscle fatigue changes joint torque during sprinting and modifies running motions^{2,3)}. In addition, modifying running motions may suppress performance reduction through compensatory use of non-fatigued areas.

Whether synergistic muscles compensate if agonist fatigue reduces power is an interesting topic of study. Relationship between fatigue and performance have not previously been investigated in terms of jumping (consecutive 1-leg jumping). In the present study, the quadriceps femoris, an agonist, was fatigued before testing, and changes in the power expression of lower limb joints during jumping were ascertained.

II. Methods

A. Subjects

Subjects were 7 male track-and-field athletes who were skilled at jumping. Mean age, height and body weight of subjects were 21.5 ± 0.8 years, 176.2 ± 5.6 cm and 71.3 ± 5.8 kg, respectively. Consent to participate in the present study was obtained after explaining the study objective and potential pain associated with the test.

B. Test procedures

A serial test was performed to ascertain effects of knee extensor muscle group fatigue on consecutive 1-leg jumping. The test was composed of the following 3 stages : 1) after a warm-up, each non-fatigued subject was instructed to jump on 1 leg 5 times on a force platform (Kistler : 9281type); 2) using an isokinetic muscular strength analyzer (Lumex : Cybex6000), each subject was asked to extend the knee at full strength 30 times at an angular velocity of $180^\circ/\text{s}$ and then relax until return the leg to the original position consecutively. This trial was de-

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defined as the fatigue exercise. Mean peak torques were calculated for the first 15 and the last 15 repetitions. Muscle endurance index was calculated by dividing the second-half mean by the first-half mean and multiplying by 100(%); and 3) each subject was instructed to jump on 1 leg 5 times at 1, 3 and 5 min after the end of the fatigue exercise. Jumping movements were analyzed using an optic 3-dimensional position analysis system (Oxford Metric : BICON) at a sampling rate of 120 Hz. At the same time, ground reaction force was measured at a sample rate of 1000 Hz. Air time of the 5 consecutive jumps was calculated based on ground reaction force data, and the highest jump was selected for motion analysis. Based on ground reaction force and video analyzed data, torques for the three lower limb joints were calculated. Also, in relation to the lowest point of the center of gravity during jumping, the downward phase was defined as the eccentric phase, while the upward phase was defined as the concentric phase.

C. Statistical analysis

Rate of change in jump height and joint torque was calculated for 1, 3 and 5 min after fatigue exercise using equation (1) below :

$$\text{Rate of change} = (\text{value before fatigue exercise} - \text{value after fatigue exercise}) / \text{value before fatigue exercise} \times 100(\%) \quad (1)$$

Paired one-way analysis of variance (ANOVA) was used to analyze significance of jump height and torques of the 3 lower limb joints before and 1, 3 and 5 min after fatigue exercise, and a multiple com-

parison test was used to further analyze items with significant F values. To ascertain relationships among investigated items, Pearson's correlation coefficients were calculated. Values of $p < 0.05$ were considered statistically significant.

III. Results

Muscle endurance index calculated in this study was $78.7 \pm 6.3\%$ (Mean \pm S. D.)

Table 1 shows mean torques of the hip, knee and ankle joints in the eccentric and concentric phases and jump height before and 1, 3 and 5 min after fatigue exercise. Jump height was significantly lower at 1 and 3 min after fatigue exercise than before fatigue exercise. Jump heights were significantly higher at 3 and 5 min than at 1 min after fatigue exercise. Significant changes in joint torque were seen for the hip and knee joints. Hip joint torque was significantly higher in the concentric phase at 5 min after fatigue exercise compared to before fatigue exercise. Compared to before fatigue exercise, knee joint torques in the eccentric and concentric phases at 1, 3 and 5 min after fatigue exercise were significantly lower.

Figure 1 shows the relationships between rate of change in the knee joint torque and jump height at 1, 3 and 5 min after fatigue exercise. Only at 1 min after fatigue exercise, significant correlations were identified between rate of change in jump height and rate of change in torque in the eccentric phase ($p < 0.05$) and concentric phase ($p < 0.01$).

Table 1. Jump height and lower limbs joint torques before and 1, 3 and 5 min after fatigue exercise.

Variable	pre	1 min	3 min	5 min	Variance analysis	multiple comparison	
Jump height (m)	0.267 \pm 0.036	0.201 \pm 0.026	0.240 \pm 0.034	0.246 \pm 0.044		Pre>3min>1min, 1min<3 · 5min	
Joint torque/Body weight (Nm/kg)							
Hip	Eccentric	2.50 \pm 0.57	2.66 \pm 1.23	2.74 \pm 1.33	3.19 \pm 0.84	*	pre<5min
	Concentric	1.59 \pm 0.16	1.61 \pm 0.74	1.63 \pm 0.90	1.97 \pm 0.68		
Knee	Eccentric	1.85 \pm 0.39	1.10 \pm 0.22	1.23 \pm 0.48	1.37 \pm 0.32	***	Pre>1min · 3min · 5min
	Concentric	1.75 \pm 0.52	1.16 \pm 0.49	1.06 \pm 0.48	0.88 \pm 0.46	***	Pre>1min · 3min · 5min
Ankle	Eccentric	3.24 \pm 0.44	2.94 \pm 0.58	3.27 \pm 0.36	3.35 \pm 0.38		
	Concentric	3.37 \pm 0.87	2.94 \pm 0.27	2.96 \pm 0.21	3.04 \pm 0.39		

*** : $p < 0.001$, * : $p < 0.05$, < > : $p < 0.05$

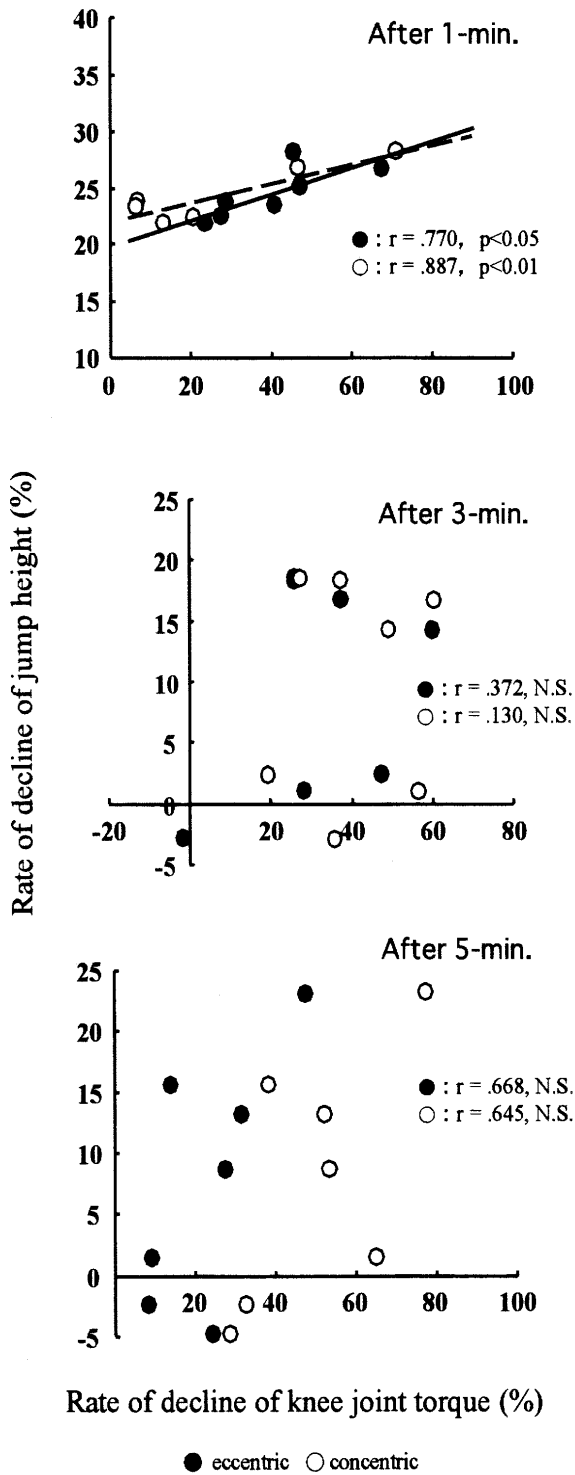


Fig. 1. Relationships between rate of decline of knee joint torques and jump height.

III. Discussion

Knee joint torques were significantly lower in eccentric and concentric phases at 1, 3 and 5 min after fatigue exercise than before exercise, suggesting that muscle fatigue did not recover within 5 min and torque expression during jumping remained low.

The greater the rate of change in knee joint torque 1 min after fatigue exercise, the greater the rate of change in jump height, suggesting that fatiguing the knee extensor muscle group, the agonist for jumping, reduces knee extension torque during jumping and lowers jump height (Fig. 1).

Although knee joint torque remained significantly low at 3 and 5 min after fatigue exercise, no significant relationships were noted between rate of change in torque and rate of change in jump height. This is because at 3 min after fatigue exercise, reduced knee joint torque was somehow compensated for by the other 2 joints.

At 5 min after fatigue exercise, no significant changes in jump height were noted and values were almost recovered to pre-fatigue levels. However, knee joint torque in the eccentric and concentric phases remained significantly low. Hip joint torque in the eccentric phase was significantly greater, and this change appears to have contributed to recovery of jump height. The 3 lower limb joints perform different roles during jumping, but all 3 joints affect each other through kinetic chains^{4,5)} and inter-joint energy flow^{6,7)}. Kigoshi et al.¹⁾ reported that hip extension power of the downward phase in drop jump grounding affects ankle joint torque in the subsequent upward phase through power transmission of the biarticular muscles. In the present study, no significant increases were seen in ankle joint torque, and increases in hip joint torque could have somehow affected the function of the other two joints to recover jumping power. In this manner, compensatory increases in hip-joint torque at 5 min after fatigue exercise were due to the feedback mechanisms compensating for fatigued muscles by recruiting other muscles.

IV. Conclusions

The present results indicate that even when the knee extensor muscle group, the agonist for jumping, is fatigued and knee extension torque during jumping has not recovered, compensatory torque from the hip joint increases jumping power.

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