FATIGUE AFFECTS THE FREQUENCY CONTENT OF THE GROUND REACTION FORCES, BUT NOT MAGNITUDE, IN DROP LANDING TASKS

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The aim of this study was to investigate the changes in the lower extremity kinematics, ground reaction forces, and frequency content of the vertical ground reaction forces between two fatigue protocols in a landing task. Eight trained male participants were instructed to perform drop-jump landings before and after two randomly fatigue protocols, namely, long-term running and functional short-term fatigue protocols. We found that the functional short-term fatigue protocol would induce an increase in hip and knee flexion, which resulted in a more flexed landing posture. Furthermore, the functional short-term fatigue protocol would decrease amplitudes in lower frequencies while increasing amplitudes in higher frequencies. These results will provide a preliminary reference for the selection of fatigue protocols in laboratory tests.

KEY WORDS: fatigue protocol, kinematics, GRF frequency, impact force, landing

INTRODUCTION: Numerous studies have shown that prolonged and high-intensity exercises induce neuromuscular fatigue of the human body. Altered neuromuscular control strategies during fatigue potentially contribute to increased risk of sports injury (Enoka, 2012). Some differences in the sagittal joint kinematics of the hip and knee at different times between pre-fatigue and post-fatigue were observed, but none in the measures of ground reaction forces (GRFs). However, no scientific consensus has been reached yet to suggest which type of fatigue protocol results in increased biomechanical changes in the lower extremity during landing movement (Quammen et al., 2012). The purpose of this study was to determine the changes in the lower extremity kinematics, ground reaction forces, and frequency content of the vertical ground reaction forces between two fatigue protocols in a landing task.

METHODS: Eight trained male athletes (age: 21±1.1 years, height: 176.4±4.7 cm, mass: 70.8±6.3 kg) volunteered to participate in the study. Two fatigue protocols, namely, long-term running and functional short-term fatigue protocols, were randomly used to induce fatigue. The long-term running fatigue protocol required participants to run at 4.0 m/s on a treadmill until exhaustion. A participant was considered to have reached maximal fatigue when he exhibited one of the following criteria: 1) his heart rate reached 90% of his age-based calculated maximum heart rate, and 2) he was unable to continue running. The functional short-term fatigue protocol required participants to first perform five consecutive countermovement jumps within a height above 70% of their maximal vertical jump height. They subsequently completed the short-term fatigue protocol that consists of a group of shuttle runs (6×10 m) with their maximal effort. Participants repeated the said process until the average height of five consecutive countermovement jumps was below 70% of their maximal vertical jump height. Before and after the fatigue protocols, each participant was required to execute five successful trials of drop landings from a 60 cm platform. The 3D kinematics (Vicon, 240 Hz) of the dominant leg and ground reaction force (GRF) (Kistler, 1200 Hz) were measured simultaneously. The main variables included 1) the sagittal joint kinematics of the hip, knee, and ankle; 2) the peak vertical ground reaction force (vGRF), the peak loading rate (determined by the maximum slope of adjacent points of vGRF) and the time to reach the above two measures during the impact phase of landings; 3) the frequency content of the vGRF (GRFs were collected at 1200 Hz). vGRFs from the stance phase were zero padded to equal 1,024 data points. An FFT was performed on each trial and then normalized to 1 Hz bins. Subjects within the dominant leg were performed to assess differences in amplitude at frequencies from 1 Hz to 50 Hz). Paired tests were used to determine the influence of independent variable (fatigue) on each of the dependent variables in the two separated fatigue protocols using SPSS 13.0 (SPSS Inc., Chicago, IL, USA). The significance level was set at $\alpha = 0.05$.

RESULTS: 1) For kinematics, the results of post-tests using functional fatigue protocol showed a significant decrease in the minimum angle of the hip ($p = 0.008$) and knee ($p = 0.028$) joints, and an increase in the range of motion of these two joints (hip: $p = 0.004$; knee: $p = 0.002$) compared with the results of pre-tests. However, no significant differences in the lower extremity kinematics (pre- vs. post-test) using the long-term running fatigue protocol were found. 2) For impact forces, no changes were found in the peak vGRF, peak loading rate, and the time these two indicators were reached in both pre- and post-tests for both fatigue protocols. 3) For frequency content of the vGRF: the results of post-tests using the functional fatigue protocol showed lower amplitudes than the results of pre-tests for frequencies from 2 Hz to 13 Hz and showed a significant decrease for frequencies that range from 2 Hz to 5 Hz ($p < 0.05$). However, post-tests results showed greater amplitudes for frequencies from 14 Hz to 50 Hz (except for 21 Hz) and significant increase for frequencies that range from 42 Hz to 43 Hz and 45 Hz to 50 Hz ($p < 0.05$). For frequencies from 36 Hz to 41 Hz, post-test results showed a significantly increasing trend ($p < 0.1$). However, no significant differences in the frequency content of the vGRF using the long-term running fatigue protocol were found in pre-tests and post-tests.

Table 1
Descriptive statistics for kinematic variables (mean ± SD) at ankle, knee, and hip joints in two fatigue protocols (pre-test vs. post-test).

Joint	Angle (°)	Long-term running fatigue protocol		Functional short-term Fatigue protocol	
		Pre-test	Post-test	Pre-test	Post-test
Ankle	Maximum angle	125.9±8.4	123.9±12.3	123.8±10.5	123.8±9.1
	Minimum angle	80.2±5.2	80.6±5.9	82.8±4.9	82.4±9.3
	Range of motion	45.6±6.6	43.3±10.1	41.0±10.5	41.4±10.4
Knee	Maximum angle	164.0±5.9	160.8±10.4	158.8±6.7	160.6±7.1
	Minimum angle	94.9±19.5	88.6±26.1	87.9±18.4	75.6±20.4*
	Range of motion	69.2±15.1	72.2±17.5	70.9±14.8	85.1±14.4**
Hip	Maximum angle	147.0±10.4	142.5±16.1	143.4±9.3	144.0±13.3
	Minimum angle	103.9±29.1	94.3±35.2	93.6±22.0	80.8±22.2**
	Range of motion	43.1±19.7	48.2±19.7	49.8±15.8	62.3±15.4**

***** Significantly different between pre- and post-tests in the same fatigue protocol with $p < 0.05$.

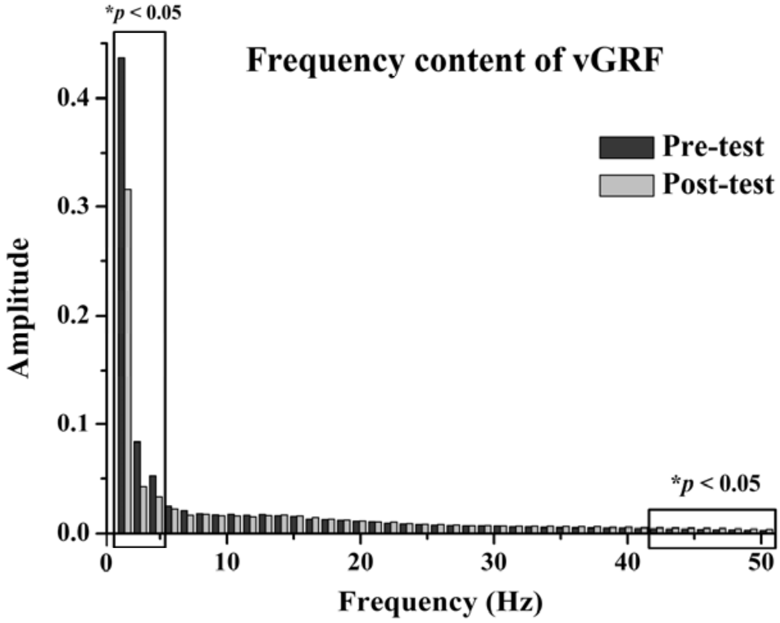

Figure 1: Amplitude spectra of the vGRF in the frequency domain compared between pre-test and post-test using the short-term fatigue protocol.

CONCLUSION: In this pilot study, we found that the functional short-term fatigue protocol would induce an increase in hip and knee flexion, except in the ankle, which resulted in a more flexed landing posture. By contrast, no significant effect of long-term running fatigue protocol was observed on sagittal kinematic changes in the lower extremity; the functional short-term fatigue protocol would decrease amplitudes in lower frequencies while increasing amplitudes in higher frequencies. Nevertheless, no significant effect of long-term running fatigue protocol was observed on the frequency content of the vGRF. These results will provide a preliminary reference for the selection of fatigue protocols in laboratory tests.

REFERENCES:

Enoka, R.M. (2012). Muscle fatigue – from motor units to clinical symptoms. *Journal of Biomechanics*, 45, 427-433.

Quammen, D., Cortes, N., Van Lunen, B. L., Lucci, S., Ringleb, S. I., & Onate, J. (2012). Two different fatigue protocols and lower extremity motion patterns during a stop-jump task. Journal of Athletic Training, 47, 32-41.

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