THE EFFECT OF KNEE FATIGUE ON SHOCK ABSORPTION DURING CUTTING MOVEMENT AFTER JUMP-LANDING

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This study aimed to investigate the effect of knee fatigue on shock absorption during cutting movements after jump-landings. Twenty-four healthy subjects performed cutting movements following jump-landings from 40 cm height, and Pre, Post-50%, and Post-30% of their pre-test measured maximum torque, used by isokinetic flexion/extension of the knee. Results showed that Post 30% fatigue were associated with decreased ROM of the knee, increased ROM of the ankle, decreased load rate, increased knee stiffness, decreased peak power of the knee, decreased work of the knee, and increased work of the ankle. We suggest that the post-30% fatigue appears to be the threshold to quantify the fatigue level. This study indicate that increases in fatigue modify the strategy shock absorption from knee to ankle in cutting movements following jump landings.

KEYWORDS: single-leg, muscle fatigue, kinematics, kinetics, landing.

INTRODUCTION: Fatigue is commonly experienced in many sports, and may be described as a reduction in maximum force production and power output, loss of exercise capacity, decreased reaction time, and an overperception of force during repeated muscle contraction (Davis & Walsh, 2010; Enoka & Duchateau, 2008; Hakkinen & Komi, 1986). It has been proposed that fatigue alters the biomechanical and neuromuscular factors associated with the risk of sustaining musculoskeletal injury(Kellis & Kouvelioti, 2009; Padua et al., 2006; Rozzi, Lephart, & Fu, 1999). Therefore, many studies have considered fatigue in their evaluation of injury mechanisms related to sport(Cortes, Greska, Kollock, Ambegaonkar, & Onate, 2013; Patrek, Kernozek, Willson, Wright, & Doberstein, 2011; Schmitz et al., 2014; Tamura et al., 2016). However, methods to quantify the effect of fatigue levels on these movements remain unclear. In addition, no study has a shock absorption strategy during cutting movement following a jump-landing, the majority of real sporting situations are associated with continuous and/or integral movements such as running, cutting, jumping, and landing. Therefore, the purpose of our study was to investigate the effect of knee fatigue on lower limb shock absorption strategy during cutting movements following jump-landings.

METHODS: Twenty-four healthy adults (13 female, age = 20.77 ± 1.01 years; height = 165.62 ± 6.51 cm; mass = 58.76 ± 6.58 kg; and 11 male, age = 21.27 ± 2.24 years; height = 179.68 ± 4.79 cm; mass = 72.20 ± 7.19 kg) volunteered for this study. Subjects were required to be healthy, with no history of orthopedic or neurologic disorder in the lower limb within the 6 months preceding data collection. Written informed consent forms were provided to all subjects, and the study was approved by the Institutional Review Board.

Nine infrared cameras (MX-T10; Vicon, UK) and one force plate (OR6-7; AMTI, USA) were used for the motion capture system and ground reaction force analysis. The sampling frequencies of the video data were set to 120 Hz and 1200 Hz for the force plate data, and the collected data were filtered by using 2nd order Butterworth low-pass filters at a cut-off frequency of 6 Hz (Decker, Torry, Wyland, Sterett, & Steadman, 2003; Pappas, Sheikhzadeh, Hagins, & Nordin, 2007). All participants wore Spandex shirts and shorts and no shoes. Twenty-six reflective markers (14 mm spherical type) were attached to the subjects using a modified Helen Hayes Marker Set.

For the landing protocol, all subjects performed the 5 jump-landings from a box with 40 cm height onto the force plate at the given signal, using their dominant lower limb, followed by a side step with the non-dominant lower limb at 45°. The dominant lower limb was identified using self-reported answers and ball kicking tests (Kellis & Kouvelioti, 2009). Arms were extended and held behind the back during the jump performance to eliminate the contribution

of the upper limbs to the landing strategy. The cutting movement following jump-landing was performed prior to the fatigue protocol, at post-50%, and post-30% fatigue levels of the maximum knee extension torque. For maximum knee-extension peak torque measurement and fatigue protocol, the range of motion of the knee joint was set from extension angle 0° to flexion angle 90° with an angle speed of 60°/s by using an isokinetic dynamometer (Cybex; HUMACNORM, CSMI, USA). Termination of the fatigue protocol was considered when knee extension peak torque < 30% occurred ≥3 consecutive times (Fagenbaum & Darling, 2003).
All statistical analyses were performed using SPSS for Windows (version 21.0, SPSS Inc., C hicago, IL). Descriptive statistical analysis (mean ± SD) was used to describe the characterist ics of each variable. After confirmation of normality, Kinematic and kinetic variables were co mpared between induced fatigue levels (pre, post-50%, and post-30%), using a one-way rep eated measures analysis of variance (ANOVA) with Bonferroni when necessary. The signific ance level was set at $p < 0.05$ for all analyses.

RESULTS: Ankle ROM was greater for the post-50% and post-30% fatigue levels, compared to pre-level ($F_{2,46} = 8.162$, $p = 0.001$). Knee ROM was smaller for the post-30% fatigue level, compared to the pre-level ($F_{2,46} = 7.671$, $p = 0.001$). Hip ROM at both post-50% and post-30 % fatigue levels was smaller, compared to the pre-level ($F_{2,46} = 16.690$, $p = 0.000$)(Table 1). Rate of loading was lower for post-50% and post-30% fatigue levels, compared to pre fatigue level ($F_{2,46} = 16.885$, $p = 0.000$). Knee stiffness was greater for the post-30% fatigue level, compared to post-50% and pre fatigue levels ($F_{2,46} = 7.557$, $p = 0.001$). Peak negative knee power identified the following trend: pre- > post-50% > post-30% ($F_{2,46} = 24.485$, $p = 0.000$)(Table 2). Work of ankle identified the following trend: post-30% > post-50% > pre- ($F_{2,46} = 27.713$, $p = 0.000$). Work of knee was greater for the post-30% fatigue level, compared to the pre-level ($F_{2,46} = 5.660$, $p = 0.006$)(Table 3).

Table 1. Results of range of motion in the lower extremities (unit: °)

	Pre	Post50%	Post30%	*F*-value	*Post-hoc*
Ankle	55.01±7.99	59.44±6.14	58.68±7.94	8.162*	2,3>1
Knee	44.89±6.35	43.45±6.05	40.78±7.99	7.671*	1>3
Hip	3.21±5.76	-0.83±5.89	-2.10±8.14	16.690*	1>2,3

All data is means ± standard deviations, The *F*-value is derived from one-way ANOVA with repeated measures within pre (1), post-50% (2), and post-30% (3),*: p<.05

Table 2. Results of peak VGRF, rate of loading, knee stiffness, and peak power of knee

	Pre	Post50%	Post30%	*F*-value	*Post-hoc*
Peak VGRF (N/kg)	28.40±1.94	27.75±2.22	28.17±1.78	2.441	ns
Rate of loading (N/kg/s)	241.11±42.09	217.12±32.84	220.67±36.20	16.885*	1>3,2
Knee Stiffness (N/kg/deg)	0.65±0.11	0.67±0.11	0.74±0.16	7.557*	3>2,1
Peak power of knee (W/kg)	-17.24±5.18	-14.87±4.66	-13.68±4.81	24.485*	1>2>3

All data is means ± standard deviations, The *F*-value is derived from one-way ANOVA with repeated measures within pre (1), post-50% (2), and post-30% (3),*: p<.05

Table 3. Results of work done in the lower extremities (unit: J·s/kg)

	Pre	Post50%	Post30%	*F*-value	*Post-hoc*
Ankle	-1.32±0.32	-1.53±0.36	-1.73±0.54	27.713*	3>2>1
Knee	-1.26±0.39	-1.22±0.38	-1.10±0.37	5.660*	1>3
Hip	-0.28±0.17	-0.31±0.17	-0.39±0.24	3.842*	ns

All data is means ± standard deviations, The *F*-value is derived from one-way ANOVA with repeated measures within pre (1), post-50% (2), and post-30% (3),*: p<.05

DISCUSSION: In our study, we identified that higher levels of knee extension fatigue were associated with decreased ROM of the knee, increased ROM of the ankle, decreased load rate, increased knee stiffness, decreased peak power of the knee, decreased work performed by the knee, and increased work performed by the ankle. Fagenbaum & Darling (2003) reported that a 25% fatigue level of knee extension peak torque resulted in a decrease in the acceleration in knee flexion, and consequently decreased knee flexion angles compared with pre-test and 50% fatigue levels during jump-landing, as we observed in our study. Kellis & Kouelioti (2009) reported that a decreased VGRF and an increased angle of the knee and hip joints with a 30% fatigue of knee extension during drop-landing. Therefore, they suggested that knee angle is substantially influenced by the fatigued muscle during a single-leg landing. Indeed, the study by Kellis & Kouelioti (2009) presented results that were, at times, different to those reported in our study. This might be related to differences in the fatigued muscle groups or fatigue protocol and landing protocol. In our study, we examined the combined effects of fatigue of both knee flexion and extension, simultaneously, rather than the separate protocols used by Kellis & Kouelioti (2009). Additionally, their study used a drop-landing task, and may have differed in the cutting movement following landing.

Previous studies have shown that: (1) knee flexion plays a key role in absorbing shock during single-landing (Ali, Robertson, & Rouhi, 2014; Kellis & Kouelioti, 2009; Yeow, Lee, & Goh, 2010), (2) knee flexion angle negatively correlates with peak VGRF (Ali, Robertson, & Rouhi, 2014), and (3) that increased knee flexion decreases the risk of ACL injury during landing (Fagenbaum & Darling, 2003; Gehring et al., 2009). Greater induced fatigue appears to reduce the ROM of the knee; thus, as the knee is the primary shock absorption structure during various landing tasks, greater fatigue may reduce the ability of the knee to absorb shock, resulting in knee injuries. In our study, complex movements, such as cutting after a jump-landing, with a substantial degree of fatigue, may compromise the shock absorption capacity of the knee, and result in injuries for not only the knee joint, but also the ankle joint. Our study identified a decrease in the capacity for shock absorption through the knee joint and subsequent compensation through the ankle joint when landing with substantial fatigue. This was directly related to a significant increase in ankle ROM and work in highly fatigued cases; thus, the ankle is also at danger of injury in cases of high fatigue (post 30%).

Previous studies have applied functional fatigue protocols, including multi-joint exercise. They suggested that the energy absorption in the lower extremity exhibits a distal-to-proximal redistribution of energy during single-leg drop landing (Coventry et al., 2006; Madigan & Pidcoe, 2003). The results of our study are different to those of Coventry et al. (2006) and Madigan & Pidcoe (2003). These differences may be attributable to the fatigue protocol. In our study, muscle fatigue was induced using an isokinetic dynamometer, the work performed by the hip exhibited no change, while that of the ankle joint had a significant increase at the post-30% fatigue level. Thus, during functional fatigue protocols using multi-joint exercises, the hip joint may play a primary role in shock absorption, however, when the fatigue was isolated to the knee joint, the ankle appears to make a substantial contribution to shock absorption. This result may also be related to characteristics associated with cutting movements following jump-landings, as used in our study.

CONCLUSION: We suggest that the post-30% fatigue level appears to be the threshold in order to quantify the fatigue level. This study indicate that increases in fatigue modify the strategy shock absorption from knee to ankle in cutting movements following jump landings.

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