THE EFFECTS OF FATIGUE DURING THE TAKE-OFF PHASE OF A BASKETBALL LAY-UP

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The purpose of the current study was to investigate the effects of fatigue during the take-off phase of a basketball lay-up. Seven recreational male athletes performed five successful lay-ups during normal and fatigued state. Fatigue was induced by repetitive maximum vertical jumps until subjects failed to reach 80% of maximum vertical jump height. Three-dimensional motion analysis was used to obtain kinematic changes during the take-off phase. Results indicated a significant difference in the knee flexion angle at the instant of contact. Fatigue had no statistical significant effect to the range of motion of knee abduction, hip flexion, ankle flexion angle, and take-off velocity. Additional external factors that affect knee kinematics during a regular basketball lay-up needs to be included as male athletes may counter the effects of fatigue during experimental control.

KEY WORDS: basketball lay-up, fatigue, jump.

INTRODUCTION: The majority of basketball related ACL injuries occur during non-contact movements (Boden, Dean, Feagin, & Garrett, 2000; Griffin, Albohm, Arendt, Bahr, Beynnon, & DeMaio, 2006; Krosshaug, Nakamae, Boden, Engebrestsen, & Smith, 2007). Boden et al. (2000) divides non-contact injuries into two mechanisms: sharp deceleration before the change of movement direction and landing. The combination of abnormal loads and altered knee motion patterns significantly increases the risk of ACL injuries (Markolf, Burchfield, Shapiro, Shepard, Finerman, & Slauterbeck, 1995). During non-contact dynamic movements, increased knee valgus angles accompanied by decreased knee flexion angles are common kinematic variables that that result in ACL injuries (Fagenbaum & Warren, 2003; Chappell, Herman, Knight, & Kirkendall, 2005; Ortiz, Olson, Etnyre, Trundelle-Jackson, Bartlett, & Venegas-Rios, 2010).

Studies have indicated knee valgus as the key variable associated to the non-contact ACL injury mechanism (e.g., Whiting & Zernicke 2008), thus factors that influence knee valgus have become of interest to researchers. Intrinsic factors, such as increased Q-angle, tibial torsion and foot pronation (Bensman, 2007), and extrinsic neuromuscular risk factors such as fatigue, muscle stiffness and muscle activation, (Griffin et al., 2006) are all observed to promote knee valgus which consequently increases the risk of ACL injuries.

Fatigue is an extrinsic factor that exacerbates the non-contact ACL injury mechanism (Chappell et al., 2005). Previous studies have indicated the effects of fatigue as a contributor to faulty knee motion patterns during landing tasks (e.g., Chappell et al., 2005). However, the effects of fatigue during the take-off phase of an athletic task remain unclear. Therefore, it may be valuable to understand kinematic changes due to fatigue prior to landing.

The purpose of this study was to present the effects of fatigue during the take-off phase of a sports specific movement, basketball lay-up. It demands athletes to utilize the non-dominant leg for take-off. We hypothesized that fatigue would result in greater peak knee abduction angle, smaller knee flexion angle, hip flexion angle, and ankle flexion angle during the braking phase of takeoff.

METHODS: A total of seven, healthy recreational male athletes (22.9 ±1.05, 1.87 ±0.06 m, 88.13 ±9.12 kg) were recruited. A recreational athlete is an individual who participates in sports non-competitively multiple times per week (Kobayshi, Kanamura, Koshida, Miyashita, Okado, & Shimizu, 2010).

Three-dimensional coordinate data were obtained to analyze the basketball layup performance with and without fatigue. Three 60-Hz digital video cameras (Cannon) in conjunction with a motion analysis system (Vicon Motus: 9.2) were used and synchronized by a Remote Video Synchronization Unit. A total of 18 markers with 14 segments were used to obtain kinematic data. Each subject was required to take a five-minute warm-up. Then, each participant was reminded of the proper technique of a five step, full speed approach for the one-footed take off lay-up. A trial was excluded when the individual missed a lay-up. The participants were only given 15 seconds between trials and two minute breaks between conditions. In total, there were 10 successful trials analyzed, five each under the fatigue and the non-fatigue state.

Fatigue was introduced by performing repetitive maximum vertical jumps before each fatigue trial. The jump and reach device (Vertec) was used to introduce fatigue, which was defined as the participants‘ failure to reach 80% of their maximum reach height three times consecutively (Weinhandl, Smith, & Dugan, 2011). After each trial the fatigue level was maintained by repeating the fatigue protocol. The video was cropped 10 frames before the foot contact for the jumping phase to the 10th frame after the instant of takeoff.

The peak knee and hip ab/adduction angle and the knee and hip flexion angles during the braking phase of the lay-up were measured. Standard t-tests were performed to compare the difference between fatigue and non-fatigue conditions. To control type I errors, Holm's correction formula was utilized to calculate new adjusted critical *P*-value = $\alpha(n - i + 1)$, where *n* is the total number of comparisons and *i* is the order of comparison. Each observed *P*-value was compared to new adjusted critical *P*-value according to the equation provided.

RESULTS: Table 1 showed statistically significant difference in knee flexion angle at initial contact. Knee joint flexion angle increased with the onset of fatigue but not for the hip or ankle. Table 2 showed no statistically significant differences in the range of motion for the three joint angles (Hip, Knee and Ankle). Take-off velocity shown in Table 2 remains to be consistent in both conditions. Peak knee ab/adduction angles (Table 3) showed no statistically significant difference due to fatigue.

Table 1: Joint flexion angles at the instant of contact during take-off phase.

Condition	Hip (degrees)	Knee (degrees)	Ankle (degrees)
Non-fatigue	29.08 ±9.05	20.99 ±5.27*	30.58 ±4.17
Fatigue	31.36 ±9.38	25.98 ±6.03	30.42 ±4.46

Note: Positive ankle flexion angle indicates plantar flexion
* indicates the significant difference with new adjusted critical *P*-value

Table 2: Range of motion and Take-off velocity.

Condition	Hip (degrees)	Knee (degrees)	Ankle (degrees)	Take-off velocity (m/s)
Non-fatigue	21.43 ±9.44	25.18 ±6.33	11.49 ±6.4	2.39 ±0.19
Fatigue	23.10 ±11.43	23.94 ±6.52	13.48 ±6.71	2.33 ±0.22

Table 3: Knee ab/adduction angles.

Condition	Peak Knee ab/adduction	Knee ab/adduction at contact
Non-fatigue	20.59 ±6.17	7.46 ±6.08
Fatigue	19.04 ±7.29	5.75 ±6.29

DISCUSSION: The only significant result was observed in the decrease of knee flexion angle at instant of contact. The results of this study may support the current ACL injury prevention model, which promotes male-like motor control strategies because male athletes demonstrate significantly less risky neuromuscular patterns (Griffin et al., 2006; Mclean & Beaulieu, 2010). Male athletes seem to exhibit a protective effect with fatigue as the knee is brought to a more neutral position because of a decreased knee flexion angle (Chappell et al., 2005; Benjaminse, Ayako, Sell, Abt, Fu, & Myers, 2008). High-risk biomechanics, particularly knee valgus, has been observed to be a key variable associated to the non-

contact ACL injury mechanism (e.g., Whiting & Zernicke 2008). Fatigue has been identified as a contributory factor to knee valgus motion however; the results of our study indicated there was no significant difference of peak knee abduction angle and knee abduction angle at the instant of contact during the take-off phase due to the effect of fatigue. There were no differences in the take-off velocity among the participants of this study. This could be due to the athletes from specific sporting backgrounds to adopt analogous jumping strategies and neuromuscular control based on the task (Laffaye, Bardy, & Durey, 2007).
The results of this study indicated no significant differences in knee valgus angles, hip flexion angles, and ankle flexion angles due to fatigue. These results were not consistent in comparison to other studies (Wikstrom, Powers, & Tillman, 2004; Chappell et al., 2005; Benjaminse et al., 2008; Ortiz et al., 2010; Weinhandl et al., 2011), which found fatigue to weaken dynamic knee joint stability and alter motor control strategies during landing from drop-jump and stop-jump tasks. The disparities between the results of our study and previous studies (Wikstrom et al., 2004; Chappell et al., 2005; Benjaminse et al., 2008; Ortiz et al., 2010; Weinhandl et al, 2011;) may be attributed to the inclusion of female participants in previous studies because female athletes display significantly more risky biomechanical variables when compared to male athletes when fatigue was considered as a factor (Fagenbaum & Warren, 2003; Ford, Myer, & Hewett, 2003; Chappell et al., 2005; Hewett, Myer, Gregory, Ford, Heidt, & Colosimo, 2005;). Additionally, the skill level of certain performance may be a limiting factor for the current study.
Our study provides evidence that male athletes demonstrate less risky motor control patterns even in fatigued state (Griffin et al., 2006; Mclean & Beaulieu, 2010). Thus, these results suggested additional factors along with fatigue to contribute to the increase risk of ACL injuries for male athletes. Complex environment of competition creates a challenging task for researchers to investigate modifiable factors. Defenders (Mclean, Lipfert, & van den Bogert, 2004) and overhead goals (Ford, Myer, Smith, Byrnes, Dopirak, & Hewett, 2005) have been shown to alter knee biomechanics. Therefore, the suggestions for the future study are to include these environmental factors for examination.

CONCLUSION: The current study found a decrease of knee flexion angle at initial contact due to fatigue. It was interesting to observe no significant knee valgus motion and consistent take-off velocities among the participants. However, participants of this study comprised of recreational male athletes all with basketball backgrounds. Therefore, when examining male athletes in experimental control accustomed to a specific athletic task, including additional yet probable factors that arise during competition may be valuable for future studies to consider.

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