

Technical Note

Activity-Specific Effects of Fatigue Protocols May Influence Landing Kinematics: A Pilot Study

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ABSTRACT

International Journal of Exercise Science 6(3) : 242-249, 2013. Fatigue is a common neuromuscular factor examined in relation to risk of ACL injury. Unfortunately, variations between the protocols used to induce fatigue in studies examining this phenomenon may have contributed to reported inconsistencies in the effects of fatigue on movements with high-risk of ACL injury. In addition, the ecological validity of fatigue experienced as a result of protocols commonly administered in the experimental setting is unclear. The purpose of this study was to examine the ecological validity, using basketball competition as the criterion measure, of two fatigue protocols commonly used to study the effect of fatigue on ACL injury risk. One male basketball player with competitive collegiate experience was recruited to participate in this study. Three dimensional angular kinematics of the lower extremity at the point of peak knee flexion were measured during a jump landing task before and after the completion of three fatigue protocols: a basketball game, a unilateral squatting and drop landing fatigue protocol, and a unilateral isokinetic knee flexion/extension fatigue protocol. We observed significant ($p < .05$) differences between fatigue protocols in knee flexion, knee rotation, knee abduction, hip rotation, and hip abduction during the landing task. In this study the fatigue-induced changes in landing biomechanics experienced as a result of basketball competition were not like those observed in the two fatigue protocols tested. These findings suggest that the effects of fatigue on ACL injury risk may be activity-specific and future investigations may benefit from the development of ecologically valid sport-specific fatigue protocols.

KEY WORDS: ACL-injury, drop landings, risk factors, basketball

INTRODUCTION

Fatigue is a neuromuscular factor hypothesized to be related to non-contact ACL injuries (5). Several publications have examined the effect of various fatigue protocols on the kinematics and kinetics of movements (primarily landing and cutting) which have been hypothesized as common mechanisms of ACL injury (2, 3, 7, 10, 17).

This research has led to the understanding that fatigue can alter landing kinematics in a manner that more closely resembles ACL injury mechanisms, particularly through decreased knee flexion angles and increased frontal and transverse plane knee movement (3, 5, 13, 17). Unfortunately, these studies have failed to document consistent biomechanical changes in movement patterns that can be attributable

to fatigue. The inconsistent nature of fatigue induced experimentally across studies is further demonstrated by a recent review of the literature (14).

A possible confounding factor, as well as a challenge to the ecological validity of these investigations is the neuromuscular specificity of fatigue. There is evidence that the muscle activation and force changes that occur as a result of fatigue are dependent upon the type of activity used to induce fatigue (1, 4). Methods used to induce fatigue in earlier investigations of ACL injury mechanisms include isometric squats (7), cycling (7), jogging (2), isokinetic resistance exercise, (13, 17) alternating landings and squats (3, 10), and a combination of dynamic activities (12). Due to the inherent nature of fatigue, it would be expected that the kinematic alterations resulting from these various fatigue protocols would also vary. An investigation conducted by James and colleagues (7) demonstrated this hypothesis. The researchers implemented a within-subjects cross over design to test differences in alterations in knee flexion angle during landing after participants performed an isometric squat vs. cycling fatigue protocol on separate occasions (7). There were significant differences between conditions in knee flexion angles following fatigue with the isometric squat resulting in a greater peak knee flexion angle. These findings support the notion that biomechanical changes resulting from fatigue may be specific to the protocol used to induce fatigue.

To our knowledge no studies exist to document the effect of multiple fatigue protocols administered to the same participant on hip and knee transverse and

frontal plane landing kinematics. In addition, since this area of research is interesting in understanding how fatigue may contribute to ACL injury during sport competition, we believe that it is necessary to compare the effects of experimental protocols previously used to sport participation on fatigue-induced alterations in lower extremity movement patterns. Therefore, the purpose of this pilot study was to compare the effects of two commonly used fatigue protocols to the fatigue produced during a simulated basketball game on lower extremity three-dimensional (3D) landing kinematics. A single subject analysis of the 3D kinematics of the lower extremity during a landing task was performed before and after three fatiguing activities: a basketball game, alternating unilateral drop landings and squats, and concentric knee flexion/extension exercise on an isokinetic dynamometer. We hypothesized that the fatigue protocols would produce significantly different alterations in lower extremity landing kinematics when compared to the basketball game, and these differences would be due to different levels and forms of neuromuscular fatigue.

METHODS

Participants

One male participant (age=24; BMI= 25.1) active in recreational basketball (>3 days/week) with previous collegiate competitive basketball experience and free from lower extremity injury gave informed consent to participate. The study was approved by our university's Institutional Review Board for the protection of human subjects.

Protocol

Pelvis and right lower extremity kinematics were measured using Flock of Birds (Ascension Technologies, Inc., Burlington, VT, USA) electromagnetic sensors and Motion Monitor (Innovative Sports Training, Inc., Chicago, IL, USA) software. Sensors were placed on the sacrum, distal lateral thigh, and proximal medial shank using double sided tape and elastic wrap (6). Global and segmental axes were established with the Y-axis designated as positive forward/anteriorly, the X-axis designated as positive leftward/medially, and the Z-axis positive upward/superiorly. All kinematic data were sampled at a frequency of 100 Hz (6). Consistency of the data across testing sessions was documented by control trials of standing, neutral posture. Positive rotations for each respective variable were defined as knee flexion and internal rotation, lower leg varus (knee adduction), and hip internal rotation and abduction.

The subject reported to the biomechanics lab on 3 separate occasions for testing separated by at least a week in between sessions. During the first session, after the completion of a dynamic warm up, vertical jump height (V_{max}) was measured with a Vertec device (Sports Imports, Inc., Columbus, OH, USA) to establish a baseline V_{max} . The subject was then instructed on how to complete the jump landing task and was given an opportunity to practice this task. The task required the subject to jump forward off of two feet and make contact with a vane on the Vertec positioned at a height equal to 50% of the subject's V_{max} followed by completion of a unilateral dominant limb landing onto a force plate located a horizontal distance of 70 cm from the initial position (15). Upon landing the

subject was instructed to immediately jump vertically out of the landing. This type of jump landing was chosen because one legged forward jump landings are a common mechanism of ACL injury in basketball (8, 9) and this distance is common in jump-stop movements in basketball.

The subject performed the landing task continuously with no break until 5 successful trials were recorded in pre-fatigue and post-fatigue conditions to ensure reliable lower extremity motion data (2). Trials in which the subject lost balance, did not jump out of the landing, did not land solely on the force plate, or did not touch the point marked 50% of V_{max} were considered invalid and were repeated. Immediately after the completion of pretesting, the subject completed one of three fatiguing protocols, and moved immediately into the post-test landings.

Basketball protocol: The basketball protocol involved 2 pick-up style basketball games played to 30 points with 10 players on a regulation court with 5 minutes of rest between games. A heart rate monitor (Model F-6, Polar Electro, Inc., Woodbury, NY, USA) was used to document intensity of the games. The subject participated in a total of 45 minutes and 6 seconds of basketball play and had a mean HR of 156 beats per minute. This heart rate was comparable to that reported (165 ± 9 beats per minute) for national-level players during competition (11). The delay between the termination of all fatigue protocols and the initiation of testing was standardized to 8.5 minutes for all three protocols based on the time required to get to the lab and initiate testing after the completion of the basketball game.

Squat/drop jump protocol: The squat/drop jump fatigue protocol consisted of an alternating series of 2 unilateral depth jumps from a height of 60 cm followed by 3 unilateral squats performed on the drop landing platform (10). The participant repeated this cycle on the dominant limb until he could no longer complete 3 consecutive squats to 90 degrees unassisted. Consistent with previous research the entire landing sequence was completed in a 20 second time frame in order to avoid muscle recovery (10). The subject was able to complete 36 cycles of this landing activity before he could no longer complete the squats unassisted.

Isokinetic protocol: For the isokinetic fatigue condition, an isokinetic dynamometer (Biodex System 4 Pro, Biodex Medical Systems, Inc, Shirley, NY) was used to determine the subject's peak torque and induce fatigue in the dominant lower limb. The subject performed maximum effort concentric knee extension and knee flexion movements at a velocity of 180°/sec through the subject's active range of motion (17). Peak knee extension torque was determined from a series of 5 alternating quadriceps and hamstrings maximum voluntary concentric repetitions. After 2 minutes of rest the subject began the fatigue protocol of continuous sets of 10 maximum knee extension/flexion repetitions separated by 20 seconds of rest until the subject's peak knee extension torque dropped below 50% of pre-fatigue peak torque. The desired level of fatigue was achieved during the sixteenth set of this exercise protocol.

Statistical Analysis

Landing kinematic data were analyzed at the instant of peak knee flexion. Respective

values for hip adduction/abduction, and internal/external rotation, knee flexion/extension, adduction/abduction and internal/external rotation were calculated for each landing trial at the moment of peak knee flexion.

Dependent t-tests were performed to compare means between the pre-fatigue landings in the basketball and the two fatigue protocols. Dependent t-tests were also performed to determine pre-post changes in landing kinematics for each variable. Change scores (post - pre=change score) were computed for each of the five variables in each landing condition and reported. An analysis of covariance (ANCOVA) was performed for each of the dependent variables to determine mean differences between landing conditions with post-fatigue landing angles as the dependent variable and pre-fatigue landing angles as the covariate to control for any pre-fatigue differences across conditions. Bonferroni's adjustment was used for pairwise comparisons to determine mean differences between conditions. P-values were set at 0.05 a priori for all statistical tests.

RESULTS

The participant's neutral stance across the six testing sessions had mean (SD) values of 0.8 (4.4) degrees of knee flexion, -0.2 (1.0) degrees of knee external rotation, 0.2 (7.3) degrees of knee valgus (lower leg abduction), 7.2 (5.6) degrees of hip adduction, and -0.4(.34) degrees of hip external rotation. Descriptive data for the pre-fatigue landing kinematics at the point of maximum knee flexion for the basketball protocol and the differences observed in the squat/ drop landing and isokinetic

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protocols are reported in Table 1. There were significant differences across conditions for the pre-fatigue landings, however, these differences were accounted for in the statistical analyses.

Table 1. Pre-fatigue landing kinematics at max knee flexion (M±SD) for the three fatigue protocols.

	Basketball	Squat/Drop Landings	Isokinetic Dynamometer
Knee Flexion (°)	42.7±10.2	31.9±3.3	38.4±6.2
Knee Rotation (°)	-0.5±4.4	3.1±1.6	9.2±1.6*
Knee Abduction (°)	-16.9±2.9	-10.4±1.5*	-17.2±5.7
Hip Rotation (°)	15.6±9.9	-18.6±2.6*	-10.0±5.5*
Hip Abduction (°)	17.2±9.2	-15.7±6.5*	11.4±9.5

* Significantly different than basketball landings; ($\alpha < 0.05$)

Table 2. Change (M±SD) in landing kinematics following three fatigue protocols.

	Basketball	Squat/Drop Landings	Isokinetic Dynamometer	p-value ^{1,2}
Knee Flexion (°)	11.3±7.8 ^a	-4.8±10.0 ^b	8.0±10.5 ^a	0.003
Knee Rotation (°)	4.2±2.3 ^a	14.5±2.1 ^b	-5.0±3.1 ^a	<0.001
Knee Abduction (°)	-9.7±3.3 ^a	-9.2±2.1 ^b	2.7±5.4 ^b	<0.001
Hip Rotation (°)	-26.2±12.7 ^a	-2.0±3.4 ^b	11.5±7.2 ^a	<0.001
Hip Abduction (°)	-17.6±11.4 ^a	33.3±19.3 ^{ab}	-27.7±7.1 ^b	0.008

¹p-value for mean differences in change scores between conditions. ²No significant differences exist between values that share a letter (a, b).

There were significant ($p < .05$) differences between conditions for all five of the lower extremity kinematic variables analyzed among (Table 2). Post-hoc analyses

revealed significant differences between the basketball and squat/landing conditions for all variables except hip adduction, while the differences between the basketball and isokinetic condition were only present in knee and hip adduction.

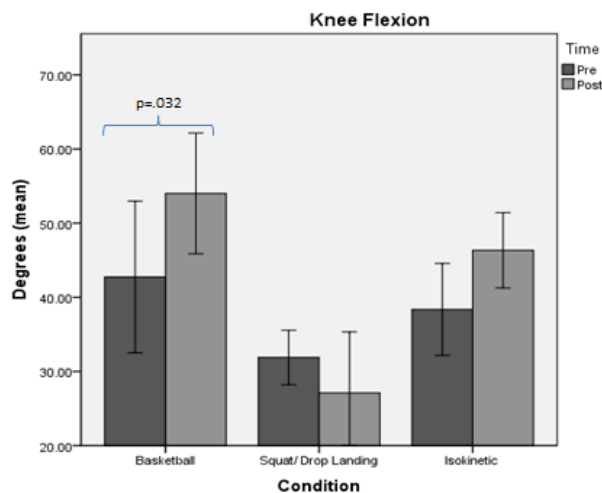


Figure 1. Pre-post changes in knee flexion for three fatigue conditions.

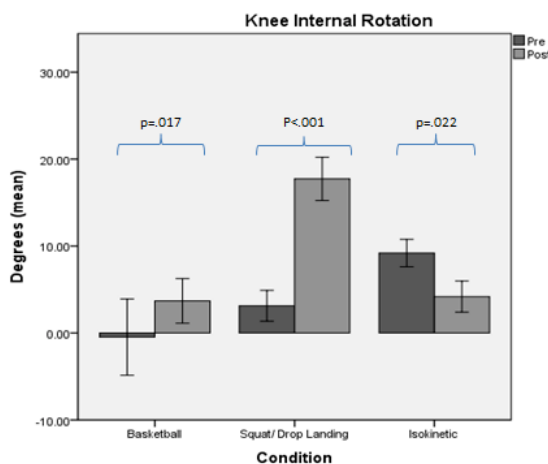


Figure 2. Pre-post changes in knee internal rotation for three fatigue conditions.

Fatigue after the basketball game led to significant increases in knee flexion ($p = 0.032$) while changes in peak knee flexion were not observed after the two fatigue protocols (Figure 1). All three fatigue protocols influenced transverse plane knee kinematics (Figure 2). The basketball and squat/drop landing

conditions both led to increased knee internal rotation ($p=0.017$ and $p<0.001$, respectively), while the isokinetic fatigue condition led to a more externally rotated knee ($p=0.022$) (Figure 2). Significant increases in knee adduction were observed after the basketball ($p=.003$) and squat/drop landing ($p=0.001$) conditions, while there was no change for the isokinetic condition (Figure 3). As for hip variables the basketball condition resulted in a significant increase ($p=0.01$) in hip external rotation (Figure 4). The basketball and isokinetic conditions led to hip adduction ($p=0.026$ and $p=0.001$, respectively), while the squat/drop landing condition led to an increase ($p=0.018$) in hip abduction (Figure 5).

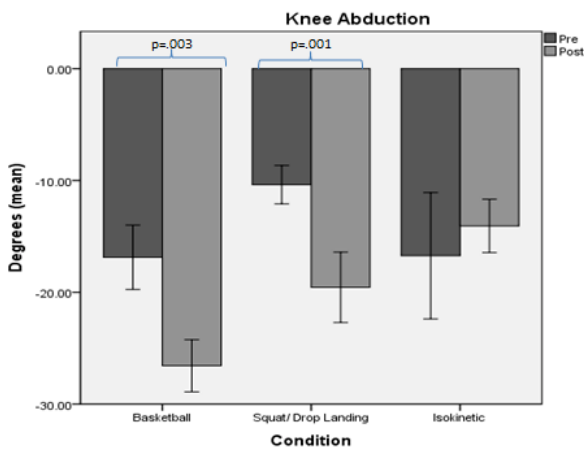


Figure 3. Pre-post changes in knee abduction for three fatigue conditions.

DISCUSSION

The purpose of this study was to compare the effects of fatigue induced by basketball competition to fatigue observed after the performance of two common laboratory fatigue protocols. We observed significant differences in landing kinematics between the basketball and laboratory fatigue protocols for four of the five lower extremity kinematic measures. These

findings lend support to our hypothesis that fatigue induced alterations in lower extremity landing kinematics may be dependent upon the activity performed to induce fatigue.

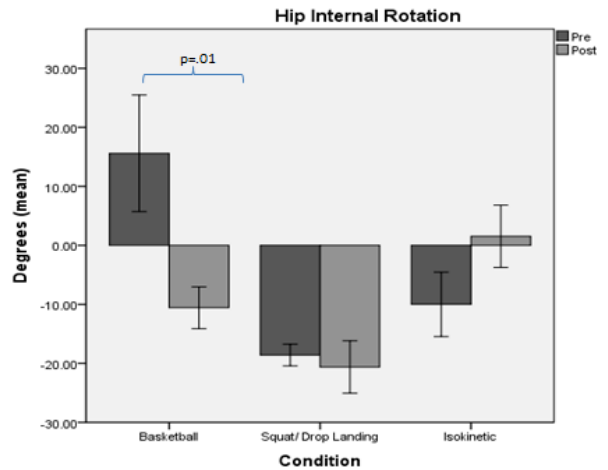


Figure 4. Pre-post changes in hip internal rotation for three fatigue conditions.

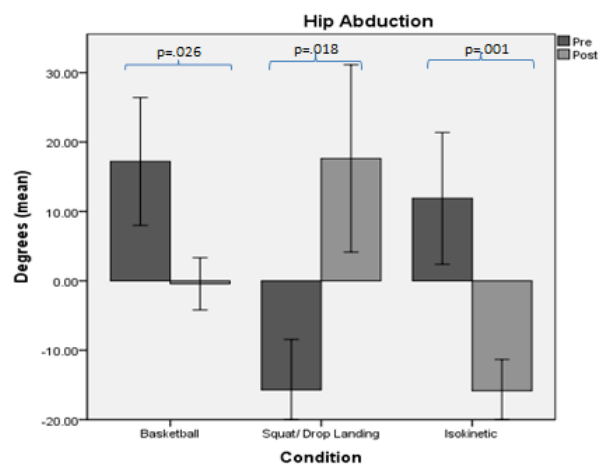


Figure 5. Pre-post changes in hip abduction for three fatigue conditions.

In our study we observed greater frontal and transverse plane knee kinematic alterations after the basketball and squat/drop landing conditions when compared to the isokinetic conditions. Alterations in frontal and transverse plan knee kinematics during landing have been implicated in ACL injury. These findings

are likely due to the fact that the isokinetic knee flexion/extension exercise required movement only along the sagittal plane, while the basketball and squat/drop landing conditions consisted of dynamic multi-planar activities. This is important with respect to previous work that has used activities isolated to the sagittal plane, because these findings suggest that these movements restricted to the sagittal plane may not induce fatigue in many of the muscles that are involved in knee stabilization that would typically be fatigued during dynamic sport participation.

It is important to note the difference in duration of time of each of the fatiguing activities. The basketball game lasted 45 minutes while the isokinetic and squat/drop landing protocols both lasted less than 15 minutes. The extent of fatigue and recovery from fatigue has been shown to be duration dependent (1), and dependent upon the type of muscle contractions that caused the fatigue (4). Both the basketball and squat/drop landing conditions consisted of high and low frequency muscle contractions, however, the duration of the basketball condition was likely to lead to a fatigue that would affect central drive and muscle activation patterns and result in a longer recovery time (4). Although the duration of activity was also likely a contributing factor observed difference in landing patterns as a result of fatigue between the basketball and isokinetic condition, the type of muscle contractions may have also played a key role. Maximum effort knee flexion and extension exercises are a series of maximal muscle contractions until the muscle can no longer maintain a preset level of force. This is very different than the other two fatigue conditions which

were composed of continuous submaximal muscle contractions. These differences would likely lead to markedly different fatigue characteristics (4), and, as a result, differences in the alterations in movement patterns.

These findings have implications for investigators interested in studying the effect of fatigue on ACL injury risk. Future research should examine the ecological validity of the fatigue protocol employed and use caution when making generalizations regarding the translation of experimental findings to the competitive sport environment. As we have demonstrated here, the alterations in movement patterns as a result of fatigue are task and duration dependent.

One limitation of the current study is that the single subject design does not allow for generalization of the result to women or other populations. At least one previous study has reported significant sex differences in response to fatigue (8), so future research examining the task dependent nature of fatigue in women is warranted. Although only one participant was utilized in the current study, we believe that the results are valid and within-subject analysis was an appropriate way to test this hypothesis. This view is supported by a recent study reporting that analysis of individual responses to landing technique may be superior to between-subject analyses due to variation in response among subjects (16).

Despite this limitation, it can be concluded that under the conditions of the current study that fatigue experienced as a consequence of basketball competition resulted in alterations to lower extremity

angular kinematics that were not like those observed after fatigue protocols that have been used frequently in previous research (10, 12, 17). Future research should explore these findings with more subjects to confirm or refute these results. If these results are confirmed future investigations on the effect of fatigue on ACL injury risk should incorporate fatigue protocols that have been validated as sport-specific and are representative of participation in the sport of interest. This work would help to provide greater insight regarding the effect of fatigue on ACL injury risk in athletic competition.

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