EVALUATING THE EFFECT OF A PERCEPTUAL-COGNITIVE TASK ON LANDING BIOMECHANICS OF THE LOWER LIMB

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The majority of anterior cruciate ligament (ACL) injuries occur without player contact following a movement such as a landing or change of direction. Much attention has been focused on muscle strengthening to delay the biomechanical effects of muscle fatigue reduce the risk of injury. However, recent studies have indicated there may be a link between cognitive factors and non-contact ACL injuries. In this study, kinematic data was acquired from seven athletes who performed jumping and landing trials. Half of the trials performed while tracking multiple virtual objects in a 3D volume, meant to simulate a game-situation cognitive load. For all participants, significant differences were observed for several angles. Increased knee abduction, which is known to increase strain on the ACL, was observed in 4 of 7 participants.

Keywords: Knee biomechanics, ACL injury, multiple-object tracking, jump/landing task.

INTRODUCTION: The anterior cruciate ligament (ACL) plays an important role in knee joint stability by limiting the anterior displacement and internal rotation of the tibia relative to the femur (Labella, C.R., Hennrikus, W., Hewett, T.E., 2014). ACL injuries are amongst the most frequent sports-related injuries (estimated between 100 000 and 200 000 per year in the United States) with a majority – between 72% and 95% – occurring without contact (Shimokochi, Y., Ambegaonkar, J.P., Meyer, E.G., Lee, S.Y., Shultz, S.J., 2013) during movements such as landing or changing of direction. Traditional injury-prevention aimed at non-contact ACL injuries has focused on delaying the onset of neuromuscular fatigue its repercussions on lower limb biomechanics.
Some recent studies have indicated that the occurrence of non-contact ACL injuries may be related to cognitive factors. For example, team-sport athletes that suffered a non-contact ACL-injury were shown to have significantly lower pre-injury scores in all categories of the ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing) cognitive test, when compared to non-injured athletes (Swanik, C.B., Covassin, T., Stearne, D.J., Schatz, P., 2007). A study of 1,718 athletes over a 20 year period showed that most injuries were non-contact and a majority occurred in competition despite much more time being spent in practice (Kobayashi et al., 2010). One hypothesis for this fact is the higher mental stress incurred during competition. It is difficult to study biomechanics in real game-situations. Previous studies have used a 3D multiple object tracking (MOT) task to simulate the cognitive task required of team-sports athletes in game situation (Faubert and Sidebottom, 2012). However, the link between the cognitive load and biomechanical changes remains unclear.
The purpose of this study is to investigate the effect of a simulated game-situation cognitive load on lower limb biomechanics during a landing task, particularly as related to straining of the ACL.

METHODS: Experimental protocol: Seven athletes (6 male and 1 female) who compete at a college level in a landing sport (soccer, football, volleyball) have participated in the study thus far. All participants were free of any lower limb injury or pathology and had not

participated in any strenuous physical exercise in the 24 hours before participation. Participants had no condition and were taking no medication that might affect alertness. They were 22.8 ± 1.9 years of age, 82.2 ± 13.5 kg and 177.1 ± 5.8 cm high. Informed written consent was obtained from each participant prior to commencement of the study.
Participants performed a series of 16 single-leg landing trials following a protocol similar to that proposed by (McLean and Samorezov, 2009). Starting from a marked position located 1m behind a pair of force plates, participants were required to jump forward, land on one leg and proceed to immediately make a lateral cutting manoeuvre and land with the contralateral leg within the limits of the second force plate. As participants initiated their movement, they broke a virtual plane at the starting position, triggering an audio cue that randomly indicated which leg they should land on. These unanticipated movements were used to add complexity by avoiding pre-planned movements. A trial was deemed successful if both of the participant's feet landed entirely within the surface of each of the force plates.
For half of the individual landing tasks, determined randomly, the participant was asked to simultaneously perform a MOT task. The take-off was executed after the first targets movements. This task consisted of five steps. Eight spheres are randomly shown in a 3D virtual volumetric space (a); then 4 of them, the targets, are highlighted for 1 second (b); all spheres return to their original form and move with dynamic interactions (crisscrossing and bouncing off of each other and the virtual 3D volume cube walls) for 8 seconds (c); movement stops and the participant has to identify the 4 targets (d); the actual targets are revealed (e). This perceptual-cognitive task aims to replicate the task of tracking teammates, opponents and the game ball (or puck) in team sports such as soccer, hockey, basketball and volleyball (Faubert and Sidebottom, 2012). Faubert and Sidebottom showed a positive correlation between the speeds at which athletes can successfully track the spheres and sport performance. Indeed, professional athletes have higher speed thresholds than high-level amateurs. These targets were displayed using a short-throw 3D projector (Viewsonic, PJD8333s) projecting on a 110-inch screen situated 1.30 meters in front of the participants, who were wearing 3D glasses.

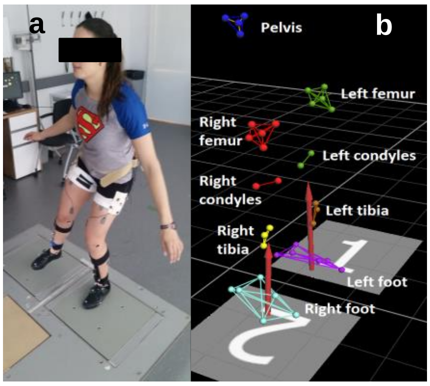

Figure 1: (a) A participant wearing reflective motion capture markers and EMG electrodes (results not presented); (b) Motion capture landmarks as displayed in Vicon Nexus software.

Lower-limb kinematic and kinetic data were recorded during all landing tasks. Thirty-six markers placed over specific lower-limb bony landmarks. Rigid bodies were used for the tibia, femur and pelvis and individual markers were placed on the feet and femoral condyles (**Figure 1a**). Ten high-speed (300 Hz) motion analysis cameras (Vicon Motion Systems Ltd., Oxford, UK) were used to record lower limbs kinematics. Landings were performed on two separate multi-axis AMTI force plates (OR6-7, Advanced Mechanical Technology Inc, Watertown, MA) that recorded ground reaction forces.

Data analysis: The unfiltered lower limb kinematics were expressed as flexion/extension, abduction/adduction and internal/external rotation angles at the hip and knee joints. Joint centers and coordinate systems were established in accordance with previous work from our group (Hagemeister et al., 2005). Kinematic data presented are of the limb on which the participants landed from the forward leap, normalized from the point of initial ground contact to toe off of the cutting manoeuvre. Data analysis is focused on the first 50% of stance as non-contact ACL injuries occur early in the stance phase (Griffin et al., 2006). Data were analyzed using a repeated single subject design and independent t-tests were used to identify significant ($p<0.05$) differences between the isolated and the cognitive load (MOT) conditions.

RESULTS: Preliminary results for knee and hip joints are presented for all participants in **Table 1** and **Table 2**, respectively. Significant differences were observed in at least one kinematic parameter for every participant. Knee abduction angle was the only parameter to be significantly effected for all participants although the effect differed between subjects: for 4 participants, MOT lead to more abduction whereas for the other 3, abduction was reduced.

Table 1 Participant mean (±S.D.) knee joint angles from 0-50% of stance

Participant	Knee joint angles					
	Flexion (°)		Abduction (°)		Rotation (°)	
	Isolated	MOT	Isolated	MOT	Isolated	MOT
1	52.5 (±14.9)	53.7 (±14.0)	8.4 (±1.3)	9.4 (±1.0)	-5.8 (±2.1)	-5.1 (±1.9)
2	50.8 (±17.8)	56.2 (±17.1)	-3.2 (±1.4)	-1.9 (±2.4)	8.1 (±3.9)	9.6 (±3.1)
3	42.1 (±9.9)	39.4 (±7.4)	5.8 (±1.4)	5.3 (±1.0)	11.0 (±2.4)	7.4 (±1.3)
4	42.8 (±13.4)	42.0 (±11.8)	-6.6 (±1.9)	-5.3 (±1.7)	5.7 (±4.5)	7.5 (±3.8)
5	41.2 (±12.5)	45.0 (±13.0)	-8.2 (±1.1)	-6.3 (±0.8)	13.4 (±6.2)	15.7 (±5.0)
6	65.6 (±16.9)	68.0 (±18.2)	1.9 (±1.3)	0.8 (±1.2)	5.9 (±4.1)	6.1 (±3.8)
7	44.5 (±15.5)	40.5 (±16.5)	-3.1 (±1.5)	-4.3 (±2.2)	14.2 (±3.6)	8.3 (±4.5)

Knee flexion, abduction and internal rotation are positive.
Shaded values indicate significant differences between isolated and MOT conditions

Table 2 Participant mean (±S.D.) hip joint angles from 0-50% of stance

Participant	Hip joint angles					
	Flexion (°)		Abduction (°)		Rotation (°)	
	Isolated	MOT	Isolated	MOT	Isolated	MOT
1	41.8 (±2.6)	36.4 (±1.7)	0.4 (±5.5)	2.2 (±3.7)	-6.1 (±2.1)	-7.7 (±1.4)
2	56.4 (±3.8)	52.5 (±3.6)	26.5 (±2.4)	17.6 (±3.5)	-4.3 (±2.2)	-5.5 (±1.0)
3	50.0 (±3.7)	46.3 (±4.6)	-2.3 (±2.1)	-2.0 (±3.0)	-3.3 (±1.6)	-4.3 (±1.9)
4	33.6 (±4.0)	27.8 (±3.4)	15.7 (±4.7)	10.6 (±3.7)	-2.1 (±2.5)	-0.7 (2.3)
5	37.2 (±2.5)	36.4 (±3.0)	15.7 (±2.3)	14.1 (±3.9)	-4.4 (±1.8)	-3.8 (±3.0)
6	66.9 (±8.7)	69.8 (±9.8)	3.6 (±4.9)	3.8 (±4.3)	-4.9 (±1.7)	-4.8 (±1.5)
7	35.6 (±2.9)	32.6 (±1.4)	10.0 (±1.5)	12.1 (±1.1)	-8.5 (±2.3)	-9.9 (±2.4)

Hip flexion, abduction and internal rotation are positive.
Shaded values indicate significant differences between isolated and MOT conditions

DISCUSSION: The addition of a perceptual-cognitive task consisting of tracking multiple objects while performing jumps and landings significantly affected the hip and/or knee biomechanics of landing in all participants. The parameter most often associated to ACL injury is knee abduction. Indeed, increased abduction leads to higher valgus loading, both of which have been shown to increase ACL loading (Chappell et al., 2005; McLean et al., 2007). In this study, knee abduction was significantly different for all subjects. For 4 of 7 participants, abduction was increased by the MOT task; for the other 3, it was lowered. Hip flexion was significantly lower for 5 of the participants and not significantly different for the others. Less hip flexion, in the absence of increased knee flexion, results in more extended limb at landing, which has also been linked to greater ACL strain in past studies (McLean et al., 2007).
While the MOT task does lead to changes in lower limb biomechanics, it is possible that the task affect individual participants in different ways. In our results, a subgroup composed of participants 1, 2, 4 and 5 showed biomechanical changes that are associated with increased ACL strain and may be more prone to injury in cognitively loaded contexts such as game-situation. Displacement of the skin-mounted markers relative to the underlying bones is a

limitation of this study, especially in light of the small differences in values such as knee abduction (< 2°).

Further investigation is required to study the link between performance in cognitive tasks such as MOT and the effect the task has on landing biomechanics. This could help identify athletes at higher risk for non-contact injury and may also be important in developing training protocols aimed to reducing the risk. It has been shown that MOT performance is a highly trainable skill and that high-level athletes have higher learning curves than non-athletes (Faubert, 2013; Faubert and Sidebottom, 2012). Improving one's skill at MOT may therefore lead to diminished effect of such a task on landing biomechanics and reduce the risk of non-contact ACL injury in real game situations.

CONCLUSION: This preliminary study quantified the effect of a perceptual-cognitive task on the knee and hip joint kinematics of a landing task. To further investigate the effect of MOT on lower-limb biomechanics, a total of 20 participants will be tested and group statistics will be applied. Knee joint moments will be also be analyzed. Understanding the relationship between cognitive loading and lower limb biomechanics is an important step in identifying athletes that may be more prone to non-contact ACL injuries and developing cognitive training protocols to lessen the effect that a game situation cognitive load has on knee joint biomechanics.

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