# TITLE

Running head: Impact of hamstring injury on ACL risk.

Title: Is there a potential relationship between prior hamstring strain injury and increased risk for future anterior cruciate ligament injury?

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## CONFLICTS OF INTEREST

NA

# ABSTRACT

Hamstring strain injuries (HSIs) are the most prevalent injury in a number of sports and whilst anterior cruciate ligament (ACL) injuries are less common they are far more severe and have long term implications, such as increased risk of developing osteoarthritis later in life. Given the high incidence and severity of these injuries they are key targets of injury preventative programs in elite sport. Evidence has shown that a previous severe knee injury (including ACL injury) increases the risk of HSI, however whether the functional deficits that occur following HSI results in an increased risk of ACL injury is yet to be considered. In this clinical commentary we present evidence that suggests that the link between previous HSI and increased risk of ACL injury requires further investigation by drawing parallels between deficits in hamstring function following HSI and in female athletes who are more prone to ACL injury than males. Comparisons between the neuromuscular function of male and female hamstring has shown that females display lower hamstring-to-quadriceps strength ratios during isokinetic knee flexion and extension, increased activation of the quadriceps compared to the hamstrings during a stop-jump landing task, a greater time required to reach maximal isokinetic hamstring torque and lower integrated myoelectrical hamstring activity during a side-step cutting manoeuvre. Somewhat similarly, in athletes with a history of HSI the previously injured limb, compared to the uninjured limb, displays lower: eccentric knee flexor strength, hamstrings-to-quadriceps strength ratio, voluntary myoelectrical activity during maximal knee flexor eccentric contraction, knee flexor eccentric rate of torque development and voluntary myoelectrical activity during the initial portion of eccentric contraction. Given the medial and lateral hamstring have different actions at the knee joint in the coronal plane, which hamstring head is previously injured might also be expected to influence the likelihood of future HSI. Whether the deficits in function following HSI, as seen in laboratory based studies, translates to deficits in hamstring function for typical injurious tasks for ACL injury is yet to be determined but should be a consideration for future work.

## KEY WORDS

Knee joint, muscle strain, injuries, trauma

## ABBREVIATIONS

ACL – anterior cruciate ligament

BF – biceps femoris

HSI – hamstring strain injury

SM – semimembranosus

ST – semitendinosus

# INTRODUCTION

Hamstring strain injuries (HSIs) are the most common injury suffered by elite athletes in a number of sports. For example, during the 2011 season of the elite Australian football competition the average incidence of HSIs per club was 4.8 per season, resulting in 16.5 player games missed per club in the same season.[1] Similar data has been reported in professional rugby league and rugby union.[2,3] In contrast, the incidence of new anterior cruciate ligament (ACL) injuries per club were significantly lower at 0.9 for Australian football and 0.4 for professional rugby union per season.[1,3] However, the consequences of ACL injury are potentially much more serious because they can result in prolonged absences from training and competition as well as an increased risk of developing osteoarthritis in later life.[4,5] Therefore, both HSI and ACL injuries present a considerable burden and risk to the success of both sporting clubs and athletes, making them key targets for prevention programs. There is evidence which points to a relationship between ACL and HSI injury.[6,7] Verrall and colleagues[7] reported that Australian footballers with a past history of severe knee injury (including injury to the ACL) displayed an odds ratio for future HSI of 5.6 (95% CI: 1.1 to 28.1). The authors postulated that these injuries, and/or the subsequent rehabilitation program, could result in altered biomechanics of the lower limbs with a resultant increase in the risk of HSI.

To our knowledge, however, very little attention has been given to the potential for previous HSI to increase the risk of sustaining an ACL injury. HSIs are known for high rates of injury recurrence, therefore recent research has focussed on the impact of HSI on neuromuscular hamstring function.[8-15] If neuromuscular hamstring function is altered following injury this may offer a possible explanation as to why HSIs are so prone to re-injury.[16] Furthermore, given hamstring function is important for 'unloading' the ACL from ground reaction force and subsequent anterior tibial translation during foot plant, it is feasible that neuromuscular dysfunction of the hamstring muscles after HSI may also lead to an increased risk of ACL injury. This theory is supported by research which has reported neuromuscular deficits in the female hamstring, and the fact that ACL injuries are far more prevalent in female athletes compared to males.[17] As such, this clinical commentary aims to present a neuromuscular case that suggests previous HSI could increase the risk of future ACL by drawing parallels in hamstring dysfunction in previously hamstring strain injured athletes and female athletes. The known mechanisms for ACL injury, the pertinent neuromuscular deficits reported in the female hamstring and the reported maladaptations associated with prior HSI will be discussed briefly. The impact of these maladaptations following HSI will then be integrated with the known deficits in neuromuscular function of the female hamstring and the reported mechanisms for ACL injury to suggest a link between prior HSI and the likelihood of future ACL injury. Finally the impact of which specific hamstring muscle is injured and how that may influence the likelihood of future ACL injury will be discussed along with what future questions need to be pursued.

## MECHANISMS OF ANTERIOR CRUCIATE LIGAMENT INJURY

Anterior cruciate ligament injury typically occurs at foot plant with concurrent low knee flexion angle, knee joint rotation and valgus collapse.[17] This kinematic profile is thought to elongate the ACL and also result in increased shear forces of the femur over the tibia resulting in greater anterior tibial translation.[17] In non-contact ACL injuries in field sports, this kinematic profile is most commonly seen when changing direction while running; specifically, when executing a sidestep cutting manoeuvre.[17-19] The balance of activation between the hamstring and quadriceps groups plays an integral role in the avoidance or realisation of the aforementioned injurious kinematic extremes.[18,20,21] Electromyography studies have shown when executing sidestep cutting manoeuvres, both hamstring and quadriceps myoelectrical activity and joint loading increases significantly.[18,21] Not surprisingly, these studies have also shown that the kinematic extremes observed when non-contact ACL injuries occur are more easily reached when total hamstring activity relative to quadriceps activity is reduced. [18,20,21] The reduced activity of the hamstrings relative to quadriceps is likely to reduce knee flexion angle; therefore increased ground reaction force will pass through the knee joint and greater shear force of the femur over tibia will ensue and, subsequently, anterior tibial translation. Thus, the strength and neuromuscular function of the hamstring muscle group is critical for the prevention of non-contact ACL injury.[17] Of further interest are the changes in activation and loading patterns of the medial (semitendinosus (ST), semimembranosus (SM)) and lateral (biceps femoris (BF)) hamstring muscles. When changes of direction are executed during running, medial and lateral hamstrings contribute differently to knee stability; ST and SM are responsible for internal rotation and varus stress about the knee, and BF for external and valgus rotation. [18,20,21] Compromised function of the medial or the lateral hamstrings will reduce net hamstring activation relative to quadriceps activation, and may lead to elongation of the ACL and potential for injury.

## NEUROMUSCULAR CHARACTERISTICS OF THE FEMALE HAMSTRING

Numerous studies have identified divergence in neuromuscular hamstring function of the female and male athlete, particularly after puberty.[22] Relevant to the proposed hypothesis, from a neuromuscular perspective these studies have examined the coactivation of the hamstrings and quadriceps, the hamstrings-to-quadrcieps strength ratio, the preactivation of the hamstrings prior to potentially injurious tasks, and the difference in lateral-to-medial hamstring activation patterns. Compared to male athletes, females have been found to display lower hamstring-to-quadriceps strength ratios during isokinetic knee flexion and extension,[23] which corroborates with observations of increased activation of the quadriceps compared to the hamstrings during a stop-jump landing task,[24] a greater time required to reach maximal isokinetic hamstring torque[25] and lower integrated electromyographical hamstring activity during a side-step cutting manoeuvre.[26]

## MALADAPTATION FOLLOWING HAMSTRING STRAIN INJURY

Previous HSI has consistently been identified as the primary risk factor for future HSI[27,28] and whilst this has been classified as a non-modifiable risk factor, several functional deficits have been identified in athletes with a history of HSI.[16] These neuromuscular maladaptations include, but are not limited to: lower eccentric knee flexor strength (10-24%);[9,10] lower voluntary myoelectrical activity during maximal knee flexor eccentric contraction (18-20%);[11,15] lower knee flexor eccentric rate of torque development (39-40%);[12] lower voluntary myoelectrical activity during the initial portion of eccentric contraction (19-25%)[12] and lower functional hamstrings-to-quadriceps ratio (19%).[9] Many of these factors, if left unattended, are purported to increase the likelihood of hamstring strain re-injury. However, only lower levels of eccentric strength have been identified as a risk factor for future injury.[29,30] Although these findings do not allow for the determination of whether these deficits are the cause of or the result of previous injury, they suggest that a previously injured limb exhibits alterations in hamstring muscle function compared to a contralateral uninjured limb. It should be noted that all of these deficits have been assessed during single joint isokinetic dynamometry and more work needs to be done assessing the impact of previous HSI on activity types with greater degrees of freedom.

## IS THERE POTENTIAL FOR AN INCREASED RISK OF NON-CONTACT ACL INJURY DUE TO HAMSTRING MALADAPTATION FOLLOWING HSI?

Optimal hamstring function may be crucial to the protection of the ACL. When compared to uninjured hamstrings or male athletes, both previously strained and female hamstrings have been shown to have lower hamstring-to-quadriceps strength ratios during isokinetic or handheld dynamometry,[9,23] lower knee flexor rate of force development during either eccentric isokinetic contractions[12] or isometric contractions[25] and lower electromyographical hamstring activity during isokinetic eccentric knee flexion[11,15] or a side-step cutting manoeuvre.[26] If these functional differences are responsible for the elevated risk to ACL injury in females, then an argument may also be made that previously strained hamstrings, and the subsequent associated functional deficits, might also increase the risk of ACL injury in athletes with a previous HSI.

From a mechanistic perspective, low levels of knee flexor strength (either absolute or relative to quadriceps strength) could result in a reduced flexion angle at the knee joint at foot plant, and consequently an increase in vertically directed ground reaction force and shearing force of the femur over the tibia. Elongation of the ligament itself from the reduced flexion angle combined with knee joint rotation and valgus collapse often observed with change of direction running is also likely to be greater. Greater force going through the knee joint, combined with a taut ligament, will likely expose the ACL to greater risk of injury.[17]

## DOES THE SPECIFIC HAMSTRING MUSCLE INJURED IMPACT ON RISK OF ACL INJURY?

One further consideration is that, whilst HSI can lead to general alterations in sagittal knee joint function, the medial and lateral hamstrings have different roles in coronal knee joint control. As such the specific hamstring muscle injured may have a direct influence on the potential increase in ACL injury risk. The BF is the hamstring muscle most commonly afflicted by strain injury.[31] The BF is responsible for knee valgus[32] and excessive knee valgus, reached through compression of the lateral aspect and distraction of the medial portion of the knee joint, has been reported as a major contributing factor to increases in loading on the ACL.[33] It might therefore be hypothesised that strain injury to the BF and the associated reductions in neuromuscular function to this muscle might actually be beneficial if it reduces the active valgus loading that the knee joint is exposed to. Indeed, compared to males, females display far greater activation of their lateral hamstrings during deceleration from a jump landing task,[32] supporting the suggestion that greater BF activation, and by extension, greater knee joint valgus loading, is a particularly injurious biomechanical profile. Contrary to this, during an unanticipated sidestep cutting manoeuvre, compared to anticipated changes of direction, which is considered less injurious, the ratio of lateral-to-medial hamstring activation decreases by nearly 30%.[18] This reduction in lateral-to-medial hamstring activation would be achieved by a greater decrease in BF activity compared to ST and SM activity, a greater increase in ST and SM activity compared to BF activity or a concurrent decline in BF activity and increase in ST and SM activity. As unanticipated side step cutting manoeuvre has been identified as an action which places the ACL at high risk of injury,[18,20] the reduction in the lateral-to-medial activation ratio might be indicative of an injurious activation pattern. Following HSI to the BF, a reduction in the activity of this muscle has been reported during isokinetic eccentric knee flexor contractions, whilst the activation of the medial hamstrings are unaffected.[11] This ultimately reduces the lateral-to-medial activation ratio. If such a neuromuscular deficit following HSI to BF, also translates to multiple joint and multiple degrees-of-freedom movements, such as side step cutting, remains to be seen and should be considered in future work. Furthermore, whilst the BF is the most commonly strained hamstring, the SM and ST can also be exposed to strain injury.[31] Because of the varus knee force applied by the medial hamstrings,[32] any deficits in neuromuscular function might be expected to increase the likelihood of a knee valgus kinematic profile and augment the risk of ACL injury. However more work needs to be done to determine if activation of the medial hamstrings is impacted upon by previous strain injury and whether this leads to more injurious kinematic profiles during potentially harmful tasks (i.e. stop landing, side step cutting etc.)

## FUTURE DIRECTION

Previous severe knee injury is known to increase the likelihood of future HSI.[7] We have suggested the possibility that prior HSI may increase the risk of future ACL injury. Evidence indicating that a limb that has suffered a previous HSI is more susceptible to ACL injury, would strengthen the proposed hypothesis. Furthermore, whether the specific hamstring muscle that was previously injured influences the risk of sustaining an ACL is worthy of consideration. Secondly, while a number of retrospective studies have examined neuromuscular knee joint function following ACL injury rehabilitation during injurious tasks that involve multiple joints and degrees of freedom, studies examining hamstring function following HSI have been largely performed using a single-joint, isokinetic model. Retrospective studies involving individuals with previously strained hamstrings, examining hamstring function during tasks which pose an inherent risk of injury to the ACL should be investigated further.

## CONCLUSION

The prevention of HSIs and ACL injuries are of great concern in elite sporting environments; however consideration of the effect of HSI on potential ACL injury has not been investigated. We propose that the maladaptation associated with a prior HSI could not only result in an increased risk of HSI recurrence but also an elevated risk of ACL injury. Future work should consider the examination of athletes with a past history of hamstring injury to determine if functional deficits related to the previously injured hamstring impact upon markers considered important for ACL injury risk. If an interrelationship is found between these two injury types it would warrant further research into the prevention and optimisation of rehabilitation for HSI as a means of reducing the risk of ACL injury.

This could potentially be beneficial at both the elite and community level and lessen the burden of secondary outcomes of ACL injury (i.e. knee osteoarthritis) on the community.

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# FIGURE LEGENDS

**Figure 1:** The foot plant at which the athlete on the left avoids injury whilst the athlete on the right sustains a non-contact ACL injury. The athlete on the left changes direction with greater knee flexion angle compared to the athlete on the right. This suggests a smaller quadriceps:hamstring moment ratio (i.e. greater quadriceps strength and activation relative to hamstring strength and activation). Thus hamstring torque relative to quadriceps torque in the athlete on the right would most likely be not as great as that for the athlete on the left. For the athlete on the right this is likely to lead to increased anterior tibial translation when the foot /lower limb is fixed; consistent with the literature.[34]