Deficits in dynamic neuromuscular control may contribute to higher anterior cruciate ligament (ACL) injury rates in female athletes. There is evidence that neuromuscular training alters muscle firing patterns, as it decreases landing forces, improves balance, and reduces ACL injury rates. This review summarises the evidence for altered muscular activation and timing relative to ACL injury risk in female athletes.

Deficits in dynamic neuromuscular control of the knee may contribute to the higher incidence of anterior cruciate ligament (ACL) injury in female athletes. There is evidence that neuromuscular training alters muscle firing patterns, as it decreases landing forces, improves balance, and reduces ACL injury rates. This review summarises the evidence for altered muscular activation and timing relative to ACL injury risk in female athletes.

Dynamic neuromuscular restraints to lower extremity joint motion include both feed forward and feedback motor control loops. Feed forward neuromuscular control, developed during previous movement, may activate muscles around the joint before excessive loading in order to absorb force and decrease stress on the ligaments. Feedback or reactive motor control strategies alter muscle activation in response to situations that load the lower extremity joints. Female subjects may display a longer latency period—that is, electromechanical delay—between preparatory and reactive muscle activation. Preparatory muscle activity can stiffen joints before unexpected perturbations. Neuromuscular training that reproduces loads similar to those encountered during competitive sports may assist in the development of both feed forward and reactive muscle activation strategies that protect the knee joint from excessive load. Plyometric exercises subject the joint to rapid loads and can activate preparatory and feedback motor control loops by adaptation of the muscle stretch receptors. Balance and core stability exercises force the athlete to tense the musculature and rapidly react to motion or perturbation.

If neuromuscular training can increase neuromuscular control of the joint and decrease knee and ACL injury risk, it is likely that the mechanisms underlying increased risk are neuromuscular in nature. Several prospective studies have shown that neuromuscular training has the potential to decrease knee injuries in general, and ACL injuries in particular, in athletes.

Abbreviations: ACL, anterior cruciate ligament; EMG, electromyographic
training may induce a “neuromuscular spurt” that may otherwise be absent in adolescent females.13–15 Training and strength differences may account for only a portion of the higher incidence of knee injury in female athletes, but lowering these high figures by even a small percentage could have a significant effect on the number of knee injuries in female athletes. Such training, if effectively implemented on a widespread basis, may help to considerably decrease the number of athletes injured each year.

The purpose of this review is to summarise the evidence for altered muscular activation and timing relative to ACL injury risk in female athletes.

Differences in Electromyographic (EMG) Activation Levels Between Male and Female Athletes

Proximal

Asymmetry of proximal muscle activation may alter the position of the knee during landing and cutting in female athletes. Decreased activation of the trunk and hip musculature may lead to lower extremity malalignment. Decreased activation of proximal stabilising muscles may lower load bearing capacity of the knee joint. Lephart et al10 report that female subjects have increased hip internal rotation during landing. Increased hip internal rotation and valgus may increase strain on the ACL.23 24 Zazulak et al12 report lower gluteal EMG activity in women than men during landing (figs 1 and 2). The proximal stabilising muscles, specifically the gluteals, control lower limb position, energy absorption, and function as powerful extensors, external rotators, and abductors of the hip during landing.8 12

Chimera et al44 evaluated the effects of plyometric training on muscle activation patterns during jump exercise and reported increased firing of the hip adductor muscles during the pre-landing phase. The experimental group showed greater preparatory adductor to abductor muscle activation. Hewett et al23 showed significant decreases in abduction/adduction moments after plyometric training. These findings delineate the role of hip muscle activation in dynamic retraction and control of lower extremity alignment.

Anterior-posterior

Female athletes show increased activation of the quadriceps relative to the antagonistic hamstring musculature.12 34 37 This disproportional recruitment of the vastus musculature increases anterior shear force at the low knee flexion angles that occur during high risk landing and pivoting movements.5 34 The quadriceps, through the anterior pull of the patellar tendon on the tibia, contribute to ACL loading when knee flexion is less than 30°.44 45 Muscular co-contraction compresses the joint, due in part to the concavity of the medial tibial plateau, which may protect the ACL against anterior drawer.38

Zazulak et al12 reported greater peak quadriceps activity in female than male subjects (fig 3). Decreased balance in strength and recruitment of the flexor relative to the extensor musculature may put the ACL at greater risk.13 Adequate co-contraction of the knee flexors is needed to balance contraction of the quadriceps, compress the joint, and control high knee extension and abduction torques.15 Appropriate hamstring recruitment may prevent the critical loading necessary to rupture the ACL during manoeuvres that place the athlete at risk of an injury.

Medial-lateral

Joint compression through muscular co-contraction allows valgus load to be carried by articular contact forces, protecting the ligaments. Decreased medial joint compression may limit passive resistance to dynamic knee valgus, predisposing the female knee to medial femoral condylar lift off and increased loads on the ACL.12 40 41 Rozzi et al7 reported that female athletes show a disproportionate (4 times greater) firing of their lateral hamstrings during landing. Myer et al12 showed a decreased ratio of medial to lateral quadriceps recruitment in female subjects (fig 4). The decreased ratio combined with unbalanced medial hamstrings recruitment may decrease control of coronal plane forces at the knee.44 45 Markolf et al34 showed that muscular contraction can decrease both the valgus and varus laxity of the knee threefold. A low ratio of medial to lateral quadriceps recruitment combined with increased lateral hamstring firing may compress the lateral joint, open the medial joint, and increase anterior shear force, which directly loads the ACL.23 34 42
Cutting manoeuvres are preplanned to counter loading in response to varus/valgus and internal/external rotation moments at the knee. The unanticipated sidestep condition was reported to increase muscle activation 10–25%, with the greatest increase before initial contact. ACL injuries occur too quickly for reflexive or voluntary muscular activation. However, preactivation may reduce the probability of injuries caused by unexpected perturbations. The lower extremity muscle activity may be 40–80% activated at the time that the foot touches the ground.44

SUMMARY AND CONCLUSIONS
Differences are observed in male and female EMG firing patterns. Decreased neuromuscular control of the trunk and lower extremity in women may increase the potential for valgus lower extremity position and increased ACL injury risk. Identification of these neuromuscular imbalances has potential for both screening of high risk athletes and targeting interventions to specific deficits. Dynamic neuromuscular training can increase active knee stabilisation and decrease the incidence of ACL injury in the female athletic population.26 31 50 51 Training may facilitate neuromuscular adaptations that provide increased joint stabilisation and muscular preactivation and reactive patterns that protect the athlete’s ACL from increased loading.30 52 53

In conclusion, there is evidence that neuromuscular training alters muscle firing patterns as it decreases landing forces, improves balance, and reduces ACL injury incidence in female athletes. Future approaches could be to use EMG analysis to assess the relative efficacy of these interventions in order to achieve the optimal effect in the most efficient manner possible. Selective combination of neuromuscular training components may provide additive effects, further reducing the risk of ACL injuries in female athletes. Additional research directions include the assessment of relative injury risk using mass neuromuscular screening. The development of screening and intervention protocols may lead to the reduction of ACL injury incidence in female athletes through the identification of the high risk female athlete subgroup that displays decreased hip and increased quadriceps muscle firing, and the correction of these neuromuscular control deficits.

ACKNOWLEDGEMENTS
We acknowledge funding support from National Institutes of Health Grant R01-AR049735-01A1 (to TEH). We also acknowledge Patricia L Ponce, PT, MS, ATC, and Stephen J Straub, PhD, ATC, for assistance with the figures. We would also like to thank Tiffany Evans for her assistance with preparation of the manuscript.

Authors’ affiliations
T E Hewett, G D Myer, K R Ford, Cincinnati Children’s Hospital, Sports Medicine Biodynamics Center, Cincinnati, OH, USA
B T Zazulak, Department of Rehabilitation Services, Yale-New Haven Hospital, New Haven, CT, USA

Competing interests: none declared

Patient consent was obtained for the publication of figure 1.

REFERENCES


