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A pilot study to determine the effect of trunk and hip focused neuromuscular training on hip and knee isokinetic strength

G D Myer,1,2 J L Brent,1 K R Ford,1,3 T E Hewett1,4

ABSTRACT
Objective: The objective was to determine the effect of trunk focused neuromuscular training (TNMT) on hip and knee strength. The hypothesis was that TNMT would increase standing isokinetic hip abduction, but not knee flexion/extension strength.

Methods: 21 high-school female volleyball players (14 TMNT, mean age 15.4 (1.4) years, weight 170.5 (5.0) cm, height 64.1 (8.5) kg and 7 controls, mean age 16.0 (1.7) years, height 173.4 (10.0) cm, weight 63.9 (5.3) kg; p=0.05) were recruited to participate in this study. The 14 TNMT subjects participated in a TNMT protocol (twice weekly) over a 10 week period in addition to their standard off-season training protocol (twice weekly) over a 10 week period in addition to their standard strength training. Standing isokinetic hip abduction strength and seated knee flexion/extension strength were measured before and after TNMT.

Results: A significant interaction of group and time was observed. The TNMT group increased ischemic hip abduction strength approximately 15% (13.5% in the dominant leg: mean (SD) 46.6 (10.1) to 52.9 (11.4) foot-pounds and 17.1% in the non-dominant leg: 46.1 (10.4) to 54.0 (10.7) foot-pounds; p=0.01). There was no difference in the control group in pre-test versus post-test measures. Post-test tests also indicated no effect of TNMT on isokinetic knee extension (p=0.57) or knee flexion (p=0.57).

Conclusions: Ten weeks of TNMT increased standing hip abduction strength in female athletes. Increased hip abduction strength and recruitment may improve the ability of female athletes to increase control of lower limb alignment and decrease knee loads resulting from increased trunk displacement during sports activities.

Female athletes are currently reported to be 4–6 times more likely to sustain a sport-related non-contact anterior cruciate ligament (ACL) injury than are male athletes.1–3 Altered neuromuscular trunk and hip control strategies during the execution of sports movements may result in lower limb joint mechanics (motions and loads) that increase the risk of ACL injury in female athletes. Hip abduction strength and control may be the critical modulator between altered trunk control and ultimately lower limb knee loads responsible for ACL rupture.

During peak growth velocity of both height and mass, the tibia and femur grow at rapid rates in pubertal athletes of both sexes.4 Rapid growth of the two longest levers in the human body initiates height increases and increased height of the centre of mass, making muscular control of trunk more challenging. In addition, increased body mass and longer joint levers leads to the development of greater joint forces and moments that are more difficult to balance and dampen at the lower limb joints during high-speed manoeuvres.5,6 Brent et al used a longitudinal study approach to determine that in a population of 11–22-year-old athletes, male athletes increased their relative hip abduction strength at a significantly greater rate than did female athletes.5 Female athletes also showed decreased power and increased valgus knee motion during jumping and landing as they matured.5,6 Mature female athletes who showed decreased hip abduction control were also more likely to show increased knee valgus angle during a dynamic cutting task.6 Based on these data, it can be hypothesised that after the onset of puberty and the initiation of peak height velocity, the increased tibia and femur lever length, with increased body mass and height of the centre of mass, lead to decreased “core stability” or control of trunk motion during dynamic tasks in the absence of increases in strength and recruitment of the musculature at the hip.7,8 As female athletes reach maturity, decreased “core stability” may underlie their tendency to increased dynamic lower limb valgus load (hip abduction and knee abduction) during dynamic tasks.5,7,11–13

The aim of the current study was to determine the effect of trunk and hip focused neuromuscular training (TNMT) on lower limb hip and knee strength. The hypothesis tested was that TNMT would change standing isokinetic hip abduction strength with no similar changes in knee flexion/extension or in the strength measures for control subjects.

METHODS
Subjects
Parents or guardians signed informed consent approved by the institutional review board and assent from the child participants were obtained before study participation.

In total, 21 high-school female volleyball players (14 TMNT, mean age 15.4 (1.4) years, weight 170.5 (5.0) cm, height 64.1 (8.5) kg and 7 controls, mean age 16.0 (1.7) years, height 173.4 (10.0) cm, weight 65.9 (5.3) kg; p=0.05) were recruited to participate in this study. The 14 TNMT subjects participated in a TNMT protocol (twice weekly) over a 10 week period in addition to their standard one-weekly off-season strength training. Pre-testing occurred 1 week before the first day of training, and post-test measures were recorded approximately 11 weeks after the pretest on all subjects.
(4 days after the final training session). The pre-established compliance criterion required that each subject participate in at least two-thirds (14 of 20) of the training sessions to be included in the study analyses.

**Dynamic strength**

Isokinetic knee extension/flexion strength was collected with subjects seated on a dynamometer with the trunk perpendicular to the floor, and with hip and knee flexed to 90°. Before each data-collection set, a warm-up set consisting of five knee flexion/extensions for each leg at 300°/second was performed (fig 1). The test session consisted of 10 knee flexion/extension repetitions for each leg at 300°/second. Peak flexion and extension torques were recorded. Hip abduction strength was measured with the subjects standing erect, fully supported with a stabilisation strap around the pelvis and their hands gripping a stable hand rest. The test leg was positioned lateral to the opposite leg at zero degrees of hip and knee flexion. The axis of abduction/adduction of the hip was aligned with the axis of rotation of the dynamometer. The resistance pad was affixed to the subject’s leg, just proximal to the knee joint. Before data collection, subjects were familiarised with how to perform the test and were allowed to perform 5–10 submaximum repetitions until they became comfortable with the testing technique and the tester confirmed appropriate technique. The athletes were then asked to perform five repetitions with maximum exertion at 120°/second (fig 2). The initial test leg was alternated between subjects to control for a side-learning effect. Peak hip abduction torques were recorded and analysed by a single investigator. The intrarater reliability (ICC3,1) for the presented hip abduction test methods showed good to excellent reliability on the left (ICC = 0.857; 95% CI 0.577 to 0.971) and right (ICC = .916; 95% CI 0.727 to 0.984) sides.

**Training protocol**

Table 1 shows the trunk and hip focused neuromuscular training protocol that was used with female athletes to target deficits in trunk control and improve hip strength and power. Five phases were used for each exercise to facilitate progression in difficulty. These exercises were designed to improve the athletes’ ability control the trunk and improve “core stability” during dynamic activities. Each exercise within the individual phases progressively increased in intensity to challenge the performance of the exercise techniques continually. End-stage progressions incorporated lateral trunk perturbations that forced the athlete to decelerate and control the trunk in the coronal plane in order to execute the prescribed technique successfully (fig 3,4). All of the exercises selected for the initial phase, before progression, were adapted from previous epidemiological studies that reported reductions in ACL injury risk (table 1).14–17 The protocol progressions were developed from previous biomechanical investigations that reported reductions in knee abduction load in female athletes after their training protocols.18–21 The novelty of this training approach is that the protocol incorporated exercises that perturb the trunk to improve control of trunk musculature, in attempt to improve hip abduction strength and “core stability.” Our hypothesis was that improved hip and trunk control would decrease the magnitude of peak kinematics and kinetics that induce high knee abduction loading in female athletes.

**Statistics**

A mixed-design, repeated-measures ANOVA (2x2x2) was used to test for the main effect and interactions of the measures of time (pre-test vs. post-test), group (trained vs. untrained control) and limb (dominant vs non-dominant) on the dependent isokinetic strength variables of (1) hip abduction, (2) knee flexion and (3) knee extension.

**RESULTS**

A significant interaction of group and time was observed with statistical analysis. The TNMT group increased bilateral isokinetic hip abduction strength approximately 15% (15.5%
Table 1  Example trunk and hip focused neuromuscular training protocol

<table>
<thead>
<tr>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
<th>Phase IV</th>
<th>Phase V</th>
<th>Exercise adapted from:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral jump and hold</td>
<td>Lateral jumps</td>
<td>Lateral hop and hold</td>
<td>Lateral hops</td>
<td>X–hops</td>
<td>Hewett 1996&lt;sup&gt;15&lt;/sup&gt; Mandelbaum 2005&lt;sup&gt;15&lt;/sup&gt;</td>
</tr>
<tr>
<td>Step–hold BDSU* (round) toe–touch swimmers</td>
<td>Jump–single-leg hold BDSU (round) swimmers with partner perturbations</td>
<td>Hop–hold Prone bridge (elbows and knees) hip extension opposed shoulder flexion</td>
<td>Hop–hop–hold Prone bridge (elbows and toes) hip extension</td>
<td>Crossover hop–hop–hold Prone bridge (elbows and toes) hip extension opposite shoulder flexion</td>
<td>Hewett 1996&lt;sup&gt;15&lt;/sup&gt; Myer 2007&lt;sup&gt;19&lt;/sup&gt;</td>
</tr>
<tr>
<td>BDSU (round) double-knee hold</td>
<td>BOSU (round) single-knee hold</td>
<td>Swiss ball bilateral knee with partner perturbations</td>
<td>Single leg 4 way BDSU (round) hop–hold</td>
<td>Swiss ball bilateral knee with lateral ball catch</td>
<td>Myer 2007&lt;sup&gt;19&lt;/sup&gt;</td>
</tr>
<tr>
<td>Single–leg lateral air ex hop–hold</td>
<td>Single-leg lateral BDSU (round) hop–hold with ball catch</td>
<td>Single leg 90° airex hop–hold reaction ball catch</td>
<td>Single leg 180° airex hop–hold reaction ball catch</td>
<td>Swiss ball hyperextensions with lateral ball catch</td>
<td>Myklebust 2003,&lt;sup&gt;17&lt;/sup&gt; Petersen 2005&lt;sup&gt;14&lt;/sup&gt;</td>
</tr>
<tr>
<td>Single tuck jump, soft landing</td>
<td>Double tuck jump</td>
<td>Repeated tuck jump</td>
<td>Side to side barrier tuck jumps</td>
<td>Side to side reaction barrier tuck jumps</td>
<td>Hewett 1996&lt;sup&gt;15&lt;/sup&gt;</td>
</tr>
<tr>
<td>Front lunges</td>
<td>Walking lunges</td>
<td>Walking lunges unilaterally weighted</td>
<td>Walking lunges with plate cross–over</td>
<td>Walking lunges with unilateral shoulder press</td>
<td>Mandelbaum 2005&lt;sup&gt;15&lt;/sup&gt; Hewett 1996&lt;sup&gt;15&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lunge jumps</td>
<td>Scissor jumps</td>
<td>Lunge jumps unilaterally weighted</td>
<td>Scissor jumps unilaterally weighted</td>
<td>Scissor jumps with ball swivel</td>
<td>Hewett 1996&lt;sup&gt;15&lt;/sup&gt;</td>
</tr>
<tr>
<td>BDSU (flat) double-leg pelvic bridges</td>
<td>BDSU (flat) single-leg pelvic bridges with weight</td>
<td>Single leg 90° airex hop–hold reaction ball catch</td>
<td>Single leg 180° airex hop–hold reaction ball catch</td>
<td>Russian hamstring curl with lateral touch</td>
<td>Myklebust 2003,&lt;sup&gt;17&lt;/sup&gt; Petersen 2005&lt;sup&gt;14&lt;/sup&gt;</td>
</tr>
<tr>
<td>Single leg 90° hop–hold</td>
<td>Single leg 90° airex hop–hold</td>
<td>Single leg 90° airex hop–hold reaction ball catch</td>
<td>Single leg 180° airex hop–hold reaction ball catch</td>
<td>Swiss ball hyperextensions with back fly</td>
<td>Myklebust 2003,&lt;sup&gt;17&lt;/sup&gt; Petersen 2005&lt;sup&gt;14&lt;/sup&gt;</td>
</tr>
<tr>
<td>BDSU (round) lateral crunch</td>
<td>Box lateral crunch with ball catch</td>
<td>Swiss ball lateral crunch with ball catch</td>
<td>Swiss ball lateral crunch with ball catch</td>
<td>Swiss ball hyperextensions with ball reach lateral</td>
<td>Myer 2007&lt;sup&gt;19&lt;/sup&gt;</td>
</tr>
<tr>
<td>Box double crunch</td>
<td>Box swivel double crunch</td>
<td>BDSU (round) swivel ball touches (feet up)</td>
<td>BDSU (round) double crunch</td>
<td>Swiss ball hyperextensions with ball reach lateral</td>
<td>Myer 2007&lt;sup&gt;19&lt;/sup&gt;</td>
</tr>
<tr>
<td>Swiss ball back hyperextensions</td>
<td>Swiss ball back hyperextensions with ball reach</td>
<td>Swiss ball hyperextensions with back fly</td>
<td>Swiss ball hyperextensions with ball reach lateral</td>
<td>Swiss ball hyperextensions with lateral ball catch</td>
<td>Myer 2007&lt;sup&gt;19&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Domed balance trainer (TEAM BOSU, Canton, Ohio, USA)

Figure 3  Example progression of training exercises targeting hip control during each phase (see table 2 for explanation).
in the dominant limb, mean (SD) 46.6 (10.1) to 52.9 (11.4) foot-pounds and 17.1% in the non-dominant limb 46.1 (10.4) to 54.0 (10.7) foot-pounds; p < 0.01). However, there were no observed effects of TNMT on isokinetic knee extension (p = 0.57) or knee flexion (p = 0.57) strength. There was no change in the control group with time between pre-test and post-test measures.

DISCUSSION

The aim of this study was to determine the effect of a training program on lower limb hip and knee strength. Hip abduction strength was increased in a group of female athletes after TNMT. Recent investigations indicate an association of hip abduction strength with dynamic valgus alignments that increase ACL injury risk. Padua et al examined the relationship between hip strength quantified with a hand-held dynamometer and joint kinematics during a drop-jump task in males and female athletes. They reported that decreased hip strength (gluteus medius and gluteus maximus) was related to greater knee valgus at initial contact and greater peak knee valgus. In addition, hip abduction strength (gluteus medius) was the only significant predictor of initial and peak valgus angles during the drop vertical jump. Claiborne et al reported a significant relationship between increased concentric hip abduction strength and reduced frontal plane knee abduction motion during a single-leg squatting task. Similarly, female athletes who showed increased eccentric isokinetic hip strength showed decreased knee valgus angles when landing from a jump. In a follow-up investigation, Jacobs et al evaluated

Figure 4  Example progression of training exercises targeting trunk control during each phase (see table 2 for explanation).
isometric hip abduction peak torque and found that female athletes showed a relationship between decreased hip strength and increased knee valgus displacement and hip adduction during landing.27 Interestingly, these relationships were not evident in the male athletes in this population study, who also showed increased hip abduction strength and decreased knee valgus displacement relative to the female athletes in the study.27

The theory that hip strength and control may dictate knee motion and loads underlines the importance of the improved hip abduction strength that was obtained from TNMT in the current project. As female athletes reach maturity, there appears to be an absence of adaptation in hip and "core" strength, concomitant with increased risk of high-risk biomechanics and increased risk of ACL injury.5 6 8 28–30 Hip abduction strength measurement may be advantageous to identify and target high-risk female athletes with neuromuscular training.25

First, the measurements of hip abduction strength quantified in the current investigation were performed in an open-chain position with concentric muscle actions. Actual ACL injury mechanisms most likely occur in closed-chain situations, with predominating eccentric muscle action at the hip. Second, there are no direct links between improved hip abduction strength and actual changes in neuromuscular strategies linked to ACL injury in female athletes. Thus, the relationships between the current findings and the potential to reduce ACL injury risk can only be inferred from these pilot data. Another potential limitation of this study is that only female volleyball players were included in the sample population. As there is a sex difference in the relative rate of ACL rupture, it is possible that inclusion of male subjects into our study design would have delineated gender differences in hip abduction strength and how these measures change with training. In addition, including athletes from different sports into the current study could have helped to show sports-specific associations for the potential to alter hip strength and been more generalisable to the overall female athletic population. Another potential limitation of this study is the lack of joint moment (torque) and electromyographic data to examine the relationship between relative torques during dynamic tasks, muscle recruitment of the prime movers at the hip, and changes in isokinetic hip abduction strength. These studies are ongoing in our laboratory and may be useful to further delineate the effectiveness of the proposed protocol. Although the aforementioned limitations may exist, there appears to be a positive relationship between increased hip abduction strength and the reduction of biomechanics linked to increased ACL injury risk, which may indicate that the reported changes are positive adaptations to tested trunk and hip focused neuromuscular training.26

<table>
<thead>
<tr>
<th>Phase</th>
<th>Hip Exercise</th>
<th>Explanation</th>
<th>Trunk Exercise</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BOSU (round) double-knee hold</td>
<td>The athlete begins this exercise by balancing in a kneeling position with her knees on each side of the round side of the BOSU. The athlete will maintain this balanced position with the hips slightly flexed for the duration of the exercise</td>
<td>BOSU (round) lateral crunch</td>
<td>The athlete starts lying on her side with her hip located in the center of the round side of the BOSU. The athlete’s feet and legs must be anchored during this exercise by the trainer or a stationary object. The athlete will proceed to bend laterally at the waist back and forth for the prescribed repetitions.</td>
</tr>
<tr>
<td>II</td>
<td>BOSU (round) single-knee hold</td>
<td>The athlete begins this exercise by balancing in a kneeling position with one knee directly in the middle of the round side of the BOSU and the other knee extended out to the side. The athlete will maintain this balanced position with the hip slightly flexed for the duration of the exercise</td>
<td>Box lateral crunch</td>
<td>Athlete starts lying on side with hip located top of a plyometric box. The athlete’s feet and legs must be anchored during this exercise by the trainer or a stationary object. The athlete will proceed to bend laterally at the waist back and forth for the prescribed repetitions</td>
</tr>
<tr>
<td>III</td>
<td>Swiss ball bilateral kneel</td>
<td>The athlete kneels and balances on Swiss ball with feet off the ground. A spotter should be available at all times in front of the athlete.</td>
<td>BOSU (round) lateral crunch with ball catch</td>
<td>Athlete starts lying on side with hip located top of the round side of a BOSU. The athlete’s feet and legs must be anchored during this exercise by the trainer or a stationary object. The athlete will proceed to bend laterally at the waist back and forth for the prescribed repetitions. A ball should be tossed back and forth with a partner to increase the difficulty of this exercise.</td>
</tr>
<tr>
<td>IV</td>
<td>Swiss ball bilateral knee with partner perturbations</td>
<td>The athlete kneels and balances on Swiss ball with her feet off of the ground. Once the athlete is stabilised the a partner can perturb the ball by kicking in unanticipated directions. A spotter should be available at all times in front of the athlete.</td>
<td>Swiss ball lateral crunch</td>
<td>Athlete starts lying on side with hip located top of a Swiss ball. The athlete’s feet and legs must be anchored during this exercise by the trainer or a stationary object. The athlete will proceed to bend laterally at the waist back and forth for the prescribed repetitions.</td>
</tr>
<tr>
<td>V</td>
<td>Swiss ball bilateral knee with lateral ball catch</td>
<td>The athlete kneels and balances on Swiss ball with feet off the ground. A ball should be tossed back and forth with a partner to increase the difficulty of this exercise</td>
<td>Swiss ball lateral crunch with ball catch</td>
<td>Athlete starts lying on side with hip located top of a Swiss ball. The athlete’s feet and legs must be anchored during this exercise by the trainer or a stationary object. The athlete will proceed to bend laterally at the waist back and forth for the prescribed repetitions. A ball should be tossed back and forth with a partner to increase the difficulty of this exercise.</td>
</tr>
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</table>
CONCLUSION

Hip abduction strength and control may be the critical modulator between altered trunk control and ultimate knee loads responsible for ACL rupture. Schmitz et al reported increased gluteus medius activation in response to trunk displacement. The results of the current study indicate that 10 weeks of TNMT increases standing hip abduction strength in female athletes. Hip abduction strength and recruitment may improve the ability of female athletes to increase control of lower limb alignment and decrease loads resulting from increased trunk displacement during sports activities. Further investigations are needed to determine if improved hip strength after TNMT translates into reduced knee abduction load in female athletes at high risk of ACL injury. If this association is observed, then parallel investigations should be undertaken to determine if TNMT is effective in pubertal and pre-pubertal athletes to determine its effectiveness to increase relative hip strength and control, which is often reduced as young female athletes mature.

Acknowledgements: This study was supported by grant R01-AR049735 from the National Institutes of Health/National Institute of Arthritis and Musculoskeletal and Skin Diseases. We thank thank the Mason School Volleyball Program, especially head coach T Keesling, Mason School athletic director S Stemple, principal Dr D Allen and superintendent K Bright for their participation in this study. We also thank athletic trainer M Moore and Middletown Regional Atrium Medical Center for their support. Superintendent K Bright for their participation in this study. We also thank athletic trainer M Moore and Middletown Regional Atrium Medical Center for their support and encouragement. K Middletown Regional Atrium Medical Center for their support. We thank the Mason School Volleyball Program, especially head coach T Keesling, Mason School athletic director S Stemple, principal Dr D Allen and superintendent K Bright for their participation in this study. We also thank athletic trainer M Moore and Middletown Regional Atrium Medical Center for their support and encouragement. K Middletown Regional Atrium Medical Center for their support and encouragement.

Competing interests: None.

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