THE EFFECT OF BIOMECHANICALLY FOCUSED INJURY PREVENTION TRAINING ON REDUCING ANTERIOR CRUCIATE LIGAMENT INJURY RISK AMONG FEMALE COMMUNITY LEVEL ATHLETES

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This study investigated changes in biomechanical risk factors following a 9-week body-weight based training intervention focused on the dynamic control of the hip/trunk. Peak knee moments and lower limb muscle activation of female community level athletes (n=18), split into intervention (n=8) and comparison (n=10) groups, were measured during unplanned sidestepping pre/post training. Following the 9-week intervention, total muscle activation of the muscles crossing the knee decreased, which was accompanied by elevated peak knee valgus and internal rotation moments among the comparison group. Increases in peak knee valgus and internal rotation moments were not observed among the training intervention group. In the context of ACL injury risk, these findings suggest that participation in biomechanically focused training may mitigate the potentially deleterious effects of regular community level sport participation.

KEYWORDS: Knee, intervention, sidestepping, injury prevention

INTRODUCTION: A review of anterior cruciate ligament (ACL) injury training literature has revealed that most published studies were not successful in decreasing non-contact ACL injury rates (Donnelly et al., 2012). Reinforcing the view that there is a need to develop more focused and biomechanically verified prevention training programmes if we are to effectively reduce an athlete’s risk of ACL injury in sport (Hewett et al., 1999). Previous biomechanical research has shown that hip and trunk dynamics during sidestepping and landing tasks are related to an athlete’s risk of sustaining an ACL injury (Donnelly et al., 2012a). This has provided a rationale to shift the focus of ACL injury prevention training from the knee towards the hip and trunk (Donnelly, 2014). Weir and colleagues (2014) recently trialed a novel biomechanically focused injury prevention training protocol with the primary goal of improving the strength of trunk and lower body musculature. A combination of plyometric, resistance and balance training exercises were used in the intervention whilst emphasising correct task specific technique. The intervention was successful in reducing peak knee valgus moments (Δ-29%, p = 0.013) and ACL injury risk among ‘high risk’ athletes during unplanned sidestepping (UnSS), and the entire training group displayed positive neuromuscular adaptations including increased gluteal total muscle activation (Δ+10%, p = 0.006). While this research established the efficacy of a biomechanically focused injury prevention programme among elite level athletes within an ideal (Donnelly et al., 2012) training environment and with 100% athlete compliance, there is a need for future research to verify its efficacy among community level athlete’s where the highest rates of ACL injury are observed (Gianotti et al., 2009).
The purpose of this study was to determine if biomechanically focused (Weir et al., 2014) ACL injury prevention training was effective in increasing lower limb muscle activation and reducing peak knee moments and the associated risk of ACL injury during the weight acceptance (WA) phase of UnSS among female community level athletes.

METHODS: Eighteen female community level athletes participated in a nine-week controlled clinical trial training intervention during a season of play. Community sports included those involving dynamic tasks such as sidestepping, single leg landing and pivoting such as field hockey, netball, basketball and soccer. Eight athletes (21.1±5.7 yrs, 1.70±0.06 m, 67.5±3.6 kg) were selected to participate in a biomechanically focused training intervention (Weir et al., 2014) adjunct to their normal in-season training (training group) and 10 athletes (19.9±3.2 yrs, 1.69±0.07 m, 63.4±10.2 kg) completed their normal in-season training (comparison group). Prior to (pre-test) and following the training intervention (post-test), all eighteen athletes completed biomechanical testing. Pre-testing was conducted during pre-season training, one to four weeks before the first competitive game. Post-testing was conducted six to eight weeks after the first competitive game. During testing a 3D motion analysis system was used to record each athlete completing a previously published sidestepping protocol (Besier et al., 2001; Donnelly et al., 2012), consisting of a series of planned and unplanned straight line running and change of direction tasks. Upper and lower body kinematics were collected using a 12 camera Vicon® MX (Oxford Metrics, Oxford, UK) system operating at 250 Hz, which was synchronized with an AMTI force plate, recording at 2,000 Hz (Advanced Mechanical Technology Inc., Watertown, MA). The activation of nine muscles was recorded with a telemetry surface electromyography (sEMG) system at 1,500 Hz (TeleMyo 2400 G2, Noraxon, Scottsdale, Arizona). Pairs of electrodes were placed over the muscle bellies of the gluteus maximus, gluteus medius, rectus femoris, vastus lateralis, vastus medialis, bicep femoris, semimembranosus, lateral gastrocnemius and medial gastrocnemius (Delagi et al., 1982). Due to telemetry problems during data collection, pre to post sEMG data was obtained from six participants in the intervention group and nine from the comparison group.

Reliable lower limb kinematic and kinetic models were used to calculate knee joint kinematics and kinetics via inverse dynamics procedures during UnSS in BodyBuilder® software using the Nexus® software pipeline (Vicon®, Oxford Metrics, Oxford, UK) (Besier et al., 2003; Donnelly et al, 2012). Following the SENIAM sEMG processing recommendations (Stegeman et al., 1999), DC offsets were removed, then band-pass filtered between 30 and 500 Hz with a zero-lag, 4th order Butterworth digital filter, full-wave rectified, then linearly enveloped using a low pass with a zero-lag, 4th order Butterworth at 6 Hz. Muscle activation was normalised to the maximal activation observed for each muscle during either dynamometry, functional and sidestepping trials and expressed as 0 – 100% maximal voluntary contraction.

Knee kinetic and muscle activation data were analysed during the WA phase of UnSS as defined by Dempsey et al., (2007). Kinetic variables included peak knee valgus, internal rotation and extension moments normalised to height and bodyweight (Ht*BW). As per Donnelly et al., (2014a), mean total muscle activation (TMA) of the gluteal, quadriceps, hamstrings and gastrocnemius groups were calculated, as well as for all muscles crossing the knee. Directed co-contraction ratios (DCCR) were calculated between muscle groups crossing the knee with flexion/extension (F/E) moment arms and medial/lateral (M/L) moment arms (Donnelly et al., 2014a). Semimembranosus/bicep femoris muscles (SM/BF) DCCR were also calculated.

A one-tailed repeated measures mixed-model ANOVA was performed to identify any significant (α = 0.05) main effects and/or interactions of each dependent variable between training intervention and comparison groups, pre to post biomechanical testing. Protected t-tests were performed as *post hoc* analyses (α < 0.05). Cohen's *d* tests were performed to determine effect sizes ($d \geq 0.60$: moderate/large effect size).

RESULTS and DISCUSSION: Surprisingly, though aligning with previous literature, both groups reported increases in UnSS peak knee moments following a playing season (Cochrane et al., 2010; Donnelly et al., 2012) (Table 1). Interestingly, the training group showed significant increases in peak knee extension moments (Δ+13%, p = 0.041), with negligible changes in frontal and transverse plane knee moments. For the comparison group, moderate increases in both peak knee valgus (Δ+27%, d = -0.36) and internal rotation moments (Δ+38%, d = -0.56) were observed, with negligible increases in sagittal plane knee moments. With it known that sagittal plane moments alone are unlikely to rupture the ACL (McLean et al., 2004), our training results suggest that adjunct biomechanically focused training maintained an athlete's relative risk of ACL injury pre to post testing, a finding not observed among athletes in the comparison group.

Pre to post biomechanical testing, both the training (Δ-15%, d = 0.45) and comparison groups (Δ-10%, d = 0.47) reported decreases in TMA of all muscles crossing the knee. These observed reductions were primarily due to reductions in gastrocnemius TMA, which was -52% (d = 0.74) in the training group and -10% (d = 0.29) in the comparison group, as well as reductions in hamstring TMA, which was -18% (d = 0.44) and -22% (d = 0.55) respectively. In the context of ACL injury risk in sport, these observed changes would be considered negative neuromuscular adaptations (Donnelly et al., 2014a; Morgan et al., 2014). When these changes in muscle activation and knee loading are considered together, it is apparent that participants in this study were at increased risk of ACL injury following a season of play, with the comparison group observing a greater change in injury risk.

Following the intervention, the SM/BF DCCR of the biomechanically focused training group were laterally redirected (BF) (d = 0.67), a result not observed in the comparison group. It has been reported previously that when the knee is flexed, as observed during the WA of UnSS, both the SM and BF have large moment arms capable of generating internal/external rotation moments about the knee (Buford et al., 2001). These observed changes in DCCR between the SM/BF may be an effective neuromuscular adaption to help support the knee against internal rotation moments and risk of ACL injury. These results may also, in part, explain why increases in peak internal rotation knee moments were not observed for the biomechanically focused training group.

Following the intervention, both the biomechanically focused training group's (d = 0.74) and comparison group's (p = 0.001) M/L DCCR were redirected laterally, which is thought to be an ineffective neuromuscular strategy to support against valgus knee moments (Donnelly et al., 2014a); the loading patterns known to elevate ACL injury risk. Though not an ideal neuromuscular adaptation, it may be inappropriate to make definitive injury risk statements based on these muscle activation changes as not all the muscles with medial (i.e. gracilis) and lateral (i.e. tensor fasciae latae) moments arms crossing the knee were included in the M/L DCCR estimates. Future research is therefore recommended to verify these neuromuscular adaptations and associated injury risk statements.

Table 1. Mean (standard deviation) normalized kinetics (Ht*BW) and electromyography (DCCR and TMA) during the WA phase of UnSS.

		Comparison Group (n = 10)		**Training Group (n = 8)**	
	Variable	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**
Kinetics	Peak Knee Extension Moment	2.13 ± 0.37[d]	2.10 ± 0.33	1.86 ± 0.32	**2.10 ± 0.30[a]**
	Peak Knee Valgus Moment	0.36 ± 0.25	0.46 ± 0.46	0.49 ± 0.26	0.45 ± 0.23
	Peak Knee Internal Rotation Moment	0.08 ± 0.05	0.11 ± 0.04	0.10 ± 0.05	0.10 ± 0.05
DCCR	F/E	-0.13 ± 0.33[d]	-0.22 ± 0.29	0.15 ± 0.33	***-0.09 ± 0.23[b]***
	M/L	0.05 ± 0.14	**-0.15 ± 0.09[a]**	0.01 ± 0.14	***-0.11 ± 0.19[b]***
	SM/BF	0.07 ± 0.36	-0.05 ± 0.32	-0.08 ± 0.33	***-0.30 ± 0.31[b]***
TMA	Gluteal	0.68 ± 0.17d	0.64 ± 0.17	0.81 ± 0.22	0.75 ± 0.38
	Quadriceps	0.89 ± 0.26	0.85 ± 0.31	0.79 ± 0.13	0.82 ± 0.26
	Hamstrings	0.47 ± 0.24	0.37 ± 0.12	0.64 ± 0.33	0.53 ± 0.18
	Gastrocnemius	0.50 ± 0.16[d]	0.46 ± 0.16[d]	0.7 ± 0.39	***0.46 ± 0.24[b]***
	Knee	1.86 ± 0.31	1.68 ± 0.46	2.13 ± 0.80	1.81 ± 0.62

All kinetic data are presented in scientific notation x10^{-1}
[a] Indicates a significant difference pre-test to post-test (p < 0.05)
[b] Indicates a greater than moderate effect size pre-test to post-test (d ≥ 0.60)
[c] Indicates a significant difference between training and comparison groups (p < 0.05)
[d] Indicates a greater than moderate effect size between training and comparison groups (d ≥ 0.60)

CONCLUSION: Increases in peak knee valgus and internal rotation moments, alongside decreases in knee TMA may leave those participating in a typical sporting season at elevated risk of ACL injury. However, participating in a biomechanically focused ACL training intervention that maintains peak knee valgus and internal rotation moments, and improves BF/ML DCCR may mitigate potential deleterious effects of regular community level sport participation.

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