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NEUROMUSCULAR ADAPTATIONS TO BALANCE AND TECHNIQUE TRAINING DURING SIDESTEPPING: IMPLICATIONS FOR ACL INJURY RISK

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This study investigated the influence of balance and technique training (BTT) on external knee joint loading and the activation of muscles crossing the knee during anticipated (AnSS) and unanticipated (UnSS) sidestepping. Twenty-eight males participated in a 28 week training intervention implemented adjunct to their regular season training. Twelve completed BTT and 16 completed a 'sham' training (ST) intervention. Knee moments and the activation of 8 muscles crossing the knee were collected during AnSS and UnSS prior to and following training. BTT did not influence the activation of the muscles crossing the knee during AnSS or UnSS. Increases in muscle activation were not proportional to increases in valgus knee moments during UnSS in both groups. Unanticipated sport tasks should be identified as distinct factors associated with ACL injury risk.

KEY WORDS: neuromuscular, ACL, injury, prevention, training, balance.

INTRODUCTION: The majority of non-contact anterior cruciate ligament (ACL) injuries occur during change-of-direction or sidestep sport tasks (Cochrane et al., 2007). Externally applied valgus, internal rotation and flexion knee moments increase *in-vivo* ACL strain (Markolf et al., 1995). Biomechanical analysis of sidestepping show that both valgus and internal rotation knee moments are elevated relative to straight line running (Besier et al., 2001; Cochrane et al., 2010; Dempsey et al., 2009). Two principles can be used to reduce external knee loading and subsequent ACL injury risk. First, reduce the loads applied to the ACL (Lloyd, 2001) by changing an individual's posture or technique during sidestepping (Dempsey et al., 2009). Second, increase the activation of muscles with moment arms capable of supporting the ACL from external knee loading when peak external forces act on the ligament (Lloyd, 2001).

Previous literature has shown that technique (Dempsey et al., 2009) and balance (Cochrane et al., 2010) training can be used to reduce valgus knee moments during sidestepping. Neuromuscular training, which contains both balance and technique training components, has been used to increase the activation of muscles supporting the knee from external loading during sidestepping (Zebis et al., 2008). Few studies however have analyzed how training influences the activation of muscles crossing the knee and external knee moments simultaneously. The purpose of this investigation was to determine if balance and technique training (BTT) implemented adjunct to normal training influences the activation of muscles crossing the knee during anticipated (AnSS) and unanticipated (UnSS) sidestepping. An additional focus of this investigation was to determine if neuromuscular changes following BTT are proportional to changes in external knee loading.

METHODS: Eight amateur level Australian Rules Football (ARF) teams (N ≈ 560) volunteered to participate in either 28 weeks of BTT (Figure 1) or a 'sham' training (ST) intervention adjunct to their regular season training. The ST intervention was designed help athletes improve their acceleration during running and served as the experimental control group.

Twenty-eight male athletes were randomly recruited in weeks -1 to 7 and 18 to 25 of their respective training interventions for biomechanical testing. Twelve participants recruited conducted BTT and 16 conducted the ST intervention (Table 1).

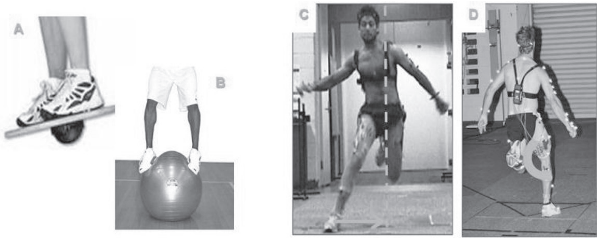

Figure 1: Example balance (A & B) training exercises used during BTT. Athletes were instructed to bring the stance foot close to midline, maintain a vertical trunk posture (C), and increase knee flexion during weight acceptance of sidestepping (D).

Table 1
Mean ± standard deviation age, body mass and height of participants used in the ST and BTT training interventions during testing session 1 and 2.

	Testing Session 1		*Testing Session 2*	
	ST (N = 16)	**BTT (N = 12)**	**ST (N = 16)**	**BTT (N = 12)**
Age (yrs)	21.2 ± 2.7	21.2 ± 3.7	21.9 ± 2.8	21.5 ± 3.1
Height (m)	1.84 ± 0.08	1.86 ± 0.09	1.84 ± 0.08	1.86 ± 0.09
Mass (kg)	81.6 ± 9.90	82.5 ± 10.2	81.4 ± 9.95	82.2 ± 10.6

During biomechanical testing participants completed the UWA sidestepping protocol (Besier et al., 2001; Dempsey et al., 2007)., which consisted of a random series of pre-planned and unplanned straight-run, crossover-cut and sidestep running tasks. Full-body 3D kinematics, ground reaction forces and surface electromyography (sEMG) of 8 muscles were measured (Figure 2).

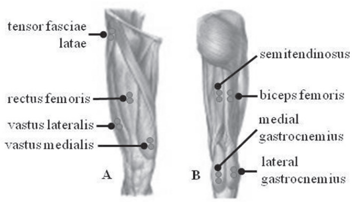

Figure 2: depiction of anterior (A) and posterior (B) sEMG placement .

Custom Bodybuilder models (VICON Peak, Oxford Metrics Ltd., UK) were used to calculate knee moments via inverse dynamics during the weight acceptance phase of stance (WA) (Dempsey et al., 2007). sEMG data were 1) band-pass filtered with a zero-lag 4th order Butterworth between 30 and 500 Hz, 2) full-wave rectified, then 3) linear envelopes were created with a low-pass zero-lag 4th order Butterworth filter at 6 Hz. Peak muscle activation during straight line running was used to normalize each muscles sEMG signal to 100% activation (Besier et al., 2003). Mean muscle activation was analyzed in a phase 50 milliseconds prior to stance leg heel contact (PC) (Besier et al., 2003).

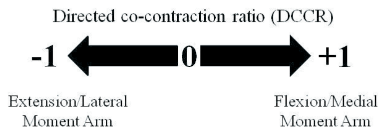

Figure 3: **DCCR characterizes co-contraction as being directed towards muscle with flexor/medial (+1) moment arms or extensor/lateral (-1) moment arms. 0 is 100% co-contraction.**

Muscle activation was assessed using a directed co-contraction ratio (DCCR) (Figure 3) and total muscle activation (TMA), which is the sum of each muscles normalized sEMG data (Heiden et al., 2009). DCCR and TMA were calculated for muscles with flexion/extension (F/E), and medial/lateral (M/L) moment arms.

A linear mixed model was used to determine experimental significance (α = 0.05) for all dependent variables. An adjusted Sidak post hoc analysis (α = 0.05) was used to assess significant main effects and interactions.

RESULTS: No significant differences in mean peak knee flexion, valgus or internal rotation moments were observed between BTT and ST groups during anticipated running (AnRun), AnSS or UnSS (Table 2). Mean peak valgus knee moments during UnSS significantly increased by 31% between testing session 1 and 2. Peak valgus knee moments showed trends of decreasing during AnSS and AnRun. Mean peak internal rotation knee moments during AnSS significantly decreased by 22% between testing sessions 1 and 2.

Table 2
Peak mean knee externally applied knee moments of both training groups across testing session 1 (T1) and 2 (T2) for AnRun, AnSS, and UnSS.

		Flexion ($Nm\cdot kg^{-1}\cdot m^{-1}$)	Valgus ($Nm\cdot kg^{-1}\cdot m^{-1}$)	Int_Rot ($Nm\cdot kg^{-1}\cdot m^{-1}$)
T 1	AnRun	1.44 ± 0.39 [a]	0.15 ± 0.10 [a]	0.15 ± 0.09 [a]
	AnSS	2.14 ± 0.55 [b]	0.37 ± 0.30 [b]	0.33 ± 0.36 [b,†]
	UnSS	2.16 ± 0.42 [b]	0.48 ± 0.27 [b,†]	0.20 ± 0.15 [a]
T 2	AnRun	1.34 ± 0.25 [a]	0.12 ± 0.08 [a]	0.13 ± 0.08 [a]
	AnSS	2.15 ± 0.42 [b]	0.35 ± 0.27 [b]	0.18 ± 0.09 [a,†]
	UnSS	2.08 ± 0.44 [b]	0.63 ± 0.40 [c,†]	0.15 ± 0.06 [a]

a,b,c Sidak adjusted post hoc comparison ($\alpha = 0.05$).
† indicates significant difference over time ($\alpha = 0.05$).

No significant differences in DCCR or TMA were observed between BTT and ST groups for all running tasks (Table 3). Co-contraction was directed towards muscles with flexion moment arms for all running tasks. Mean F/E DCCR became directed towards muscles with extension moment arms between testing session 1 and 2, meaning the relative activation of the quadriceps and tensor fasciae latae (TFL) muscles increased over time. Mean F/E TMA significantly increased between testing sessions 1 and 2 for all running tasks.
Co-contraction was directed towards muscles with medial moment arms during AnRun and lateral moment arms during AnSS and UnSS. Mean M/L TMA significantly increased between testing sessions by 25% and 22% during AnSS and 20% and 17% during UnSS for the ST and BTT groups respectively.

Table 3
PC DCCR and mean TMA of the muscles crossing the knee between testing sessions 1 (T1) and 2 (T2) for AnRun, AnSS, and UnSS.

			ST	BTT		ST	BTT
		F/E DCCR	F/E TMA	F/E TMA	M/L DCCR	M/L TMA	M/L TMA
T1	AnRun	0.6 ± 0.2 [†,a]	1.8 ± 0.4 [†,a]	2.0 ± 0.4 [†,a]	0.1 ± 0.2 [a]	1.7 ± 0.4 [†,b]	1.95 ± 0.4 [†,a]
	AnSS	0.4 ± 0.2 [†,b]	2.6 ± 0.5 [†,b]	2.9 ± 0.7 [†,b]	0.0 ± 0.2 [b]	2.4 ± 0.5 [†,b]	2.7 ± 0.7 [†,b]
	UnSS	0.2 ± 0.4 [†,c]	2.7 ± 0.9 [†,b]	2.6 ± 0.8 [†,c]	-0.1 ± 0.3 [b]	2.4 ± 0.9 [†,b]	2.4 ± 0.8 [†,c]
T2	AnRun	0.6 ± 0.2 [†,a]	2.0 ± 0.4 [†,a]	2.4 ± 0.6 [†,a]	0.1 ± 0.2 [a]	1.9 ± 0.4 [†,a]	2.2 ± 0.5 [†,a]
	AnSS	0.2 ± 0.3 [†,b]	3.2 ± 0.9 [†,b]	3.3 ± 0.7 [†,b]	-0.1 ± 0.3 [b]	3.0 ± 0.9 [†,b]	3.1 ± 0.7 [†,b]
	UnSS	0.1 ± 0.3 [†,c]	3.1 ± 1.2 [†,b]	3.0 ± 0.8 [†,c]	-0.1 ± 0.2 [b]	2.9 ± 1.2 [†,b]	2.8 ± 0.8 [†,c]

a,b,c Sidak adjusted *post hoc* comparison ($\alpha = 0.05$).
† indicates significant difference over time ($\alpha = 0.05$).

DISCUSSION: BTT implemented adjunct to regular season training was not effective in changing the activation of muscles crossing the knee during AnSS or UnSS. Results however did show that normal ARF training was effective in increasing the TMA of muscles crossing the knee and the relative activation of the quadriceps muscles during AnSS or UnSS. Pre-contact eccentric quadriceps muscle force past 20° of knee flexion can decrease *in-vivo* ACL strain during the contact phase of simulated landing (Hashemi et al., 2010). The significant increases in quadriceps muscle activation in testing session 2 during WA show that normal ARF training is effective in protecting the knee from external joint loading in the sagittal plane. Furthermore, results showed that significant time varying increases in F/E TMA during AnSS and UnSS correspond to unchanged external flexion knee moments. Sagittal plane knee moments are not the likely mechanism of ACL injury during sidestepping (McLean et al., 2004; 2008).

M/L TMA was elevated during AnSS when compared with UnSS even though valgus knee moments were lower. The relative differences in M/L TMA activation between UnSS and AnSS (ST 0%, BTT -11%) in testing session 1 did not correspond to the relative difference in external valgus knee moments observed during WA (+30%). In testing session 2, the relative difference in M/L TMA activation between UnSS and AnSS (ST -3%, BTT -10%) and external valgus knee moments (+80%) became more exaggerated. These results suggest that following an ARF season, the muscles crossing the knee are less capable of supporting the knee from externally applied valgus knee moments and subsequent ACL injury risk is elevated during UnSS.

CONCLUSION: BTT adjunct to normal ARF training was not effective in changing the activation of the muscles crossing the knee during AnSS or UnSS. The time varying increases in F/E TMA and the relative activation of the quadriceps muscles show normal ARF training is effective in protecting the knee from externally applied flexion knee moments. The contrast between increases in M/L TMA and external valgus knee moments during UnSS suggest anticipated and unanticipated sport tasks are distinct factors associated with ACL injury risk. Unanticipated sport tasks should be incorporated in the design of ACL injury prevention training protocols.

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