HOW MUCH IS ENOUGH? MAINTAINING THE BIOMECHANICAL BENEFITS OF AN ACL INJURY PREVENTION TRAINING PROGRAM

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This study investigated the effect of a 16-week *maintenance* training program which directly followed a high-dose 9 week *initial t*raining intervention, as part of a biomechanically informed ACL injury prevention program. Three-dimensional kinematic and kinetic data of elite female hockey players (n=16) were collected at baseline, post *initial* training and post *maintenance* training during unplanned sidestepping. *Maintenance* training was effective in retaining reduced peak knee valgus moments in a ‘high-risk’ subgroup elicited from the *initial* training program. Conversely, although the total group demonstrated no benefits following *initial* training, they displayed a reduction (Δ-26.3%, *g*=0.30) in peak valgus knee moments following *maintenance* training, suggesting a prolonged albeit moderate dose of training was effective for this population.

KEY WORDS: Unplanned Sidestepping, Valgus Knee Moments, Intervention.

INTRODUCTION: The majority of anterior cruciate ligament (ACL) injury prevention programs have attempted to combine various types of exercise genres (e.g. plyometric, balance, resistance) to reduce the applied moments of the knee and in turn the related risk of ACL injury. However, with more than 70% of published training intervention programs have been unsuccessful in reducing ACL injury rates in sport (Hewett et al., 1999; Mandelbaum et al., 2005; Myklebust et al., 2003; Pfeiffer et al., 2006) Donnelly et al., (2014) hypothesises that such programs may have failed to target and mitigate the biomechanical risk factors related to ACL injury risk (Donnelly et al., 2012). Donnelly and colleagues (2014) went on to propose a targeted ACL injury prevention training framework and preventative training paradigm (Donnelly, 2014) that has challenged sport scientists to consider the intended focus of injury prevention training protocols. More specifically, how can sport scientists and allied health practitioners modify the biomechanical risk factors known to elevate ACL injury risk as opposed to focusing on the type of exercises (e.g. balance vs. plyometric) used within the training protocol. Simulation studies have demonstrated that the ability to control the upper body by redirecting the whole-body centre of mass toward the intended direction of travel is directly associated with peak valgus knee moments and subsequent ACL injury risk during sidestepping (Dempsey et al., 2009; Donnelly et al., 2012; Patla et al., 1999). With this in mind, Weir and colleagues (2014) developed a 9-week biomechanically focused, high-intensity training protocol, which was designed to target the strength and dynamic control of the trunk and hip musculature. Results from this study provide pilot empirical evidence of the efficacy of a biomechanically focused hip and trunk musculature training programme for reducing ACL injury risk (i.e. reduced knee moments and improved muscle activation) among elite female field hockey players, particularly among a sub-group of athletes identified as ‘high-risk’. However, further research is necessary to establish what intensity and duration of ongoing training is required to retain and/or build upon these positive initial findings (reduced peak knee valgus moments). Therefore the aim of the present study was to examine the effectiveness of a *maintenance* training program that directly followed a successful *initial* 9 week training program (Weir et al., 2014).

METHODS: Sixteen elite female hockey players (22.1±2.3 yrs, 1.70±0.10 m, 64.3±8.1 kg) participated in a 9-week *initial* training intervention (4 x 20 minute sessions, progressing in intensity every 2 weeks) followed by a 16-week *maintenance* training program (3 x 10 minute sessions) implemented alongside the regular in-season training schedule. This multifactorial intervention encompassed body-weight based plyometric, balance and strength exercises (www.youtube.com/bodyfitworkouts), whose overriding goal was to target the dynamic control of the trunk and hip, as well as strengthen the gastrocnemius muscle group (Morgan et al., 2014). Three-dimensional (3D) motion capture of each participant undertaking a previously published sidestepping protocol (Besier et al., 2001; Dempsey et al., 2009; Donnelly, et al., 2012) were collected at baseline, following *initial* training and again following *maintenance* training (Figure 1). Marker trajectories were recorded using a 22-camera Vicon MX/T40 system at 250Hz (Oxford Metrics, Oxford, UK) and force plate data at 2,000Hz (AMTI, Watertown, MA). Upper and lower body kinematics (see Table 1) as well as peak knee extension, valgus and internal rotation knee moments were analysed during the weight acceptance (WA) phase of unplanned sidestepping (Dempsey et al., 2007). High-risk athletes were identified using a ‘responder’ analysis, determined based on a moderate-large (d≥0.5) decrease in peak knee valgus moments following *initial* training. One-way repeated measures ANOVA (α<0.05) and Hedges’ g for effect sizes were calculated pre-post *initial* training (Weir et al., 2014), post-*initial* training and post *maintenance* training and sub-group analysis between the responder group following initial training and following maintenance training. Due to sample size restrictions and to avoid the effects of dropout, intention to treat analysis was used for all cohorts.

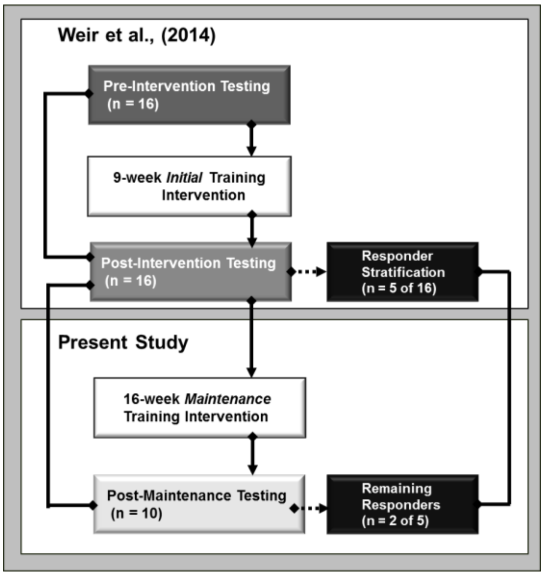

Figure 1. Biomechanical testing sessions schema outlining sample size and participant stratification.

RESULTS AND DISCUSSION: For the athlete’s classified as responders (reduced peak knee valgus moment) following the *initial 9-week* training program, the observed reductions in peak valgus knee moments were preserved following 16-week’s *maintenance* training. Peak knee extension moments increased to a small effect (Δ+18.2%, g=0.16) for this sub-group following *maintenance* training, however extension moments alone do not rupture the ACL, and therefore this is unlikely to be a clinically relevant finding (McLean et al., 2005). Interestingly, while the *initial* 9-week training program did not elicit any changes in peak valgus knee moments for the total group, clinically meaningful reduction of - 26.3% (*g*=0.30) in peak valgus knee moments were observed following 16-weeks of *maintenance* training. This suggests that a general preventative treatment effect may have been observed when the training stimulus was applied for a longer duration (i.e. increased dosage).

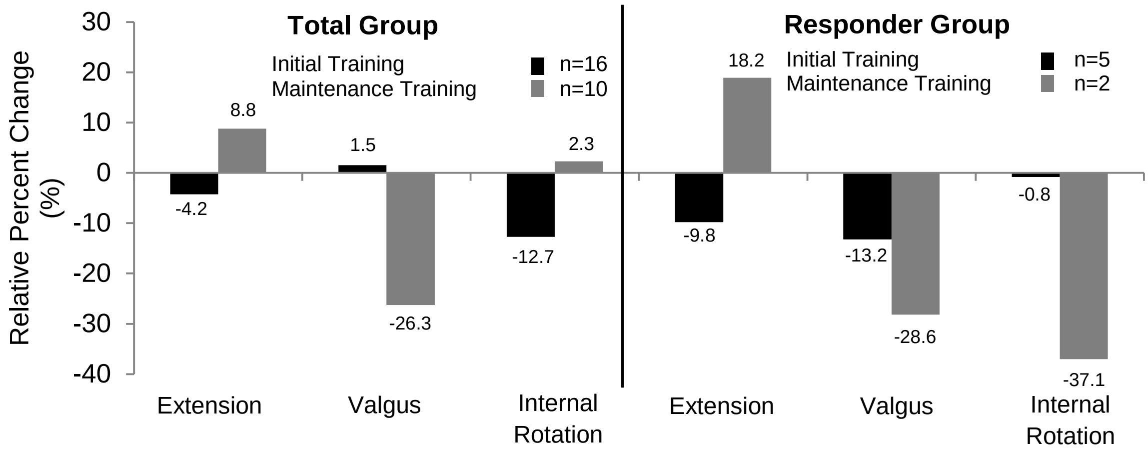

Figure 2. Relative percentage change in peak knee moments of the total group and the responder sub-group during the WA phase of unplanned sidestepping. Initial training change is the relative change in the variable result from pre- to post-intervention testing (week 0-9); and maintenance training is the relative change in the variable result from post-intervention to follow-up testing (week 9-24).

In the context of ACL injury risk, foot placement from midline was the only kinematic variable measured returning a positive change following *initial* training (∆-25%, g=0.29), however this increased returned to baseline levels at the completion of *maintenance* training (∆+42.3%, g=0.43). Kinematic strategies associated with reductions in peak knee moments are multifaceted and complex, whereby a number of solutions can effectively reduce peak valgus knee moments during unplanned sidestepping (Donnelly et al., 2012). Although not all the positive kinematic changes following *initial* training were maintained, complex system adjustments along the kinematic chain as a result of improved dynamic strength and control of the trunk and hip following both *initial* and *maintenance* training were appropriate for reducing/maintaining athletes' peak valgus knee moments and subsequent injury risk.

Table 1. Mean (SD) kinematics and spatio-temporal variables of the total and responder groups during the WA phase of unplanned sidestepping.

	***Initial* Training (Weir et al., 2014)**		
		***Maintenance* Training (Present Study)**	
	Pre-intervention	Post-intervention	Post-maintenance
Total Group	n = 15		n = 10
Trunk flexion ROM (°)	9.1 (3.3)	9.4 (2.6)	8.7 (2.0)
Peak trunk lateral flexion angle (°)	9.1 (7.7)	11.5 (10.7)	8.5 (9.6)
Knee flexion at foot strike (°)	19.2 (5.1)	18.6 (5.3)	18.1 (3.0)
Knee flexion RoM (°)	36.9 (3.6)	35.8 (5.1)	36.4 (4.6)
Mean knee flexion (°)	36.0 (4.4)	34.4 (5.7)	32.4 (3.5)
Foot displacement from midline (cm)	27.2 (2.7)	25.9 (8.3)	28.2 (1.33)
Pre-contact velocity (m/s)	4.47 (0.26)	4.39 (0.33)	4.47 (0.40)
Responder Group	n = 5		n = 2
Trunk flexion ROM (°)	10.5 (1.5)	9.4 (3.1)	10.1 (0.6)
Peak trunk lateral flexion angle (°)	13.9 (2.7)	15.0 (6.5)	12.4 (2.3)
Knee flexion at foot strike (°)	20.9 (4.4)	20.6 (6.8)	16.4 (2.4)
Knee flexion ROM (°)	36.5 (2.4)	35.9 (5.8)	38.0 (8.2)
Mean knee Flexion (°)	37.6 (2.8)	36.5 (5.5)	30.3 (3.6)
Foot displacement from midline (cm)	25.8 (2.0)	19.6 (14.0) [a]	28.0 (0.6) [b]
Pre-contact Velocity (m/s)	4.69 (0.14)	4.50 (0.01)	4.44 (0.54)

[a]Indicates a moderate effect pre-intervention to post-intervention (*g* ≥ 0.30)
[b]Indicates a moderate effect post-training to post-maintenance (*g* ≥ 0.30)

CONCLUSION: 16-weeks of biomechanically focused injury prevention *maintenance* training was effective in retaining reductions in peak knee valgus knee moments during unplanned sidestepping among athletes classified as 'high-risk' following 9-weeks of similar injury prevention training (Weir et al., 2014). A reduction in peak valgus knee moments among all athletes participating in the 16-week *maintenance* training intervention suggests that if given adequate biomechanically focused training duration/volume, a generalised training effect will be observed. This is valuable information for coaches and medical staff implementing injury prevention programs in time-poor competitive season schedules.

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ACKNOWLEDGEMENTS: We would like to thank Hockey Australia, especially Jennifer Cooke and Kate Starre, and the Australian Women's field hockey team (Hockeyroos) for their involvement and participation in this research, as well as Josh 'Coach' Armstrong for the development of the training intervention.