Physical Therapy in Sport xxx (2012) 1–5

Contents lists available at SciVerse ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original research

Effects of a lower limb functional exercise programme aimed at minimising knee valgus angle on running kinematics in youth athletes

Kelly R. Sheerin*, Patria A. Hume, Chris Whatman

AUT Running Mechanics Clinic, Sports Performance Research Institute New Zealand, School of Sport and Recreation, Auckland University of Technology, Private Bag 92006, Auckland, New Zealand

ARTICLE INFO

Article history:
Received 31 August 2011
Received in revised form
20 December 2011
Accepted 23 January 2012

Keywords:
Gait
Intervention
Children
Functional training

ABSTRACT

Objectives: To investigate the effectiveness of 8-weeks of lower limb functional exercises on frontal plane hip and knee angles during running in youth athletes.
Design: Pre- and post-intervention quantitative experimental.
Methods: Nineteen athletes (11 male, 8 female, 11.54 ± 1.34 years) from a long-term athletic development programme had 3-dimensional running gait measured pre and post an 8-week exercise intervention. Youth athletes randomised to control (upper limb strengthening exercises) or experimental (lower limb functional exercises aimed at minimising knee valgus angle) interventions completed the exercises during the first 10 min of training, three mornings a week. Pre- and post-parallel groups' analysis provided estimates of intervention effects for control and experimental groups.
Results: Differences in pre- to post-intervention changes in mean frontal plane angles between control and experimental groups were trivial for the left hip (0.1°) and right knee (−0.3°). There was a small beneficial decrease in right hip joint angle (0.4°) but a very large (ES = 0.77, CI 0.1–3.7) detrimental increase in left knee valgus angle (1.9°) between groups.
Conclusion: The 8-week lower limb functional exercises had little beneficial effects on lower limb hip and knee mechanics in youth athletes aged 9–14 years.

1. Introduction

To achieve proficiency and elite performance, athletes are undertaking intense training at younger ages, participating in multiple sports in one season, and continuing training throughout the entire year. However, with increases in volume and intensity of training there have also been increases in athletic injuries in the youth athletic population (Seto, Statuta, & Solari, 2010). The majority of injuries sustained by youth athletes are mild, causing only minor discomfort. However, moderate injuries can result in significant pain and time out of sports, while serious injuries can lead to a complete drop out of participation. Sporting injuries in youth can also have a flow-on effect, whereby athletes may not achieve the success they are capable of, as well as the potential to develop disability, such as chronic pain or arthritis later in adulthood (Adirim & Cheng, 2003).

Many sports involve an element of running, and overuse injuries common in youth athletes such as patello-femoral pain syndrome and iliotibial band friction syndrome have been linked to faulty running mechanics (Powers, 2010). Lower limb alignment, as well as hip muscle dysfunction have been identified as potential contributing factors to such injuries (Powers, 2010). Although guidelines exist to help youth athletes reduce the risk of injury (Micheli, Glassman, & Klein, 2000), they are largely non-specific, and there is a call for more research to help minimise the risk for youth athletes. Improving the understanding of the factors contributing to the development of running related overuse injuries is desirable, so that ultimately clear injury prevention strategies can be developed (Adirim & Cheng, 2003; Shanmugam & Maffulli, 2008; Stein & Micheli, 2010).

Gluteus medius, and to some extent tensor fascia lata, are active during the stance phase of running, corresponding to a hip abduction moment (Mann, Moran, & Dougherty, 1986). At footstrike, these muscles act eccentrically to control hip adduction, and then concentrically from the support phase into propulsion to create hip abduction (Mann et al., 1986). If proximal instability exists, the lower limb could move into more hip adduction, creating an increased valgus angle at the knee, which in turn could place the runner at an increased risk for lower limb injury (Ferber, Davis, Hamill, Pollard, & McKeown, 2002). Frontal plane hip and knee

* Corresponding author. Tel. +649 921 9999x7354, fax +649 921 9960.
E-mail addresses: kelly.sheerin@aut.ac.nz (K.R. Sheerin), patria.hume@aut.ac.nz (P.A. Hume), chris.whatman@aut.ac.nz (C. Whatman).

1466-853X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ptsp.2012.01.003

angles are useful variables for screening youth athletes given the proposed links between excess lower limb frontal plane motion and the development of lower limb overuse injuries (Powers, 2010).

Altered or decreased lower limb control identified in runners with overuse injuries (Ferber, Noehren, Hamill, & Davis, 2010; Milner, Hamill, & Davis, 2010), is also highlighted as a risk factor for anterior cruciate ligament (ACL) injury during dynamic sporting actions (Hewett, Myer, Ford, Heidt, Colosimo, & McLean, 2005). Lower limb functional training with a focus on correcting lower limb alignment and improving lower limb strength can not only reduce the levels of potential biomechanical risk factors for ACL injury, but also decreases knee and ACL injury incidence in female athletes (Hewett, Ford, & Myer, 2006). Programmes including exercises such as double and single leg squats, and lying and standing hip abductor muscle strengthening have been used with children to reduce risk of ACL injury as a result of jumping activities. Other studies reporting exercises such as broad jumps and jump squats could also be useful for lower limb functional training in children (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Myer, Chu, Brent, & Hewett, 2008; Presswood, Cronin, Keogh, & Whatman, 2008), but no studies have looked at the effects of this type of training on running mechanics.

It is postulated that if knee valgus can be reduced, and lower limb alignment can be improved during running, athletes will no longer be in a risk position for the development of overuse injuries. Therefore, the aim of this study was to investigate the effectiveness of an 8-week lower limb functional exercise programme on frontal plane hip and knee angles in youth athletes aged 9–14 years.

2. Methods

The AUT University Ethics Committee gave approval for this study to proceed. Youth athletes and their guardians provided written consent and completed a self-report injury questionnaire. No youth athletes had an injury that would impact on running performance at the time of data collection.

Nineteen (11 male and 8 female) youth athletes, ranging in age from 9 to 14 years, recruited from an existing long-term athletic development (LTAD) programme designed to develop all-round sporting ability completed pre- and post-intervention testing and 8-weeks of exercise intervention. The youth athletes also participated in a range of competitive sports.

Data were collected pre- and post- an 8-week intervention. Height, body mass and strength measures were recorded, and then the youth athletes warmed up by running on the treadmill (PowerJog, Birmingham, UK) for 5 min reaching a self-selected comfortable pace at the end of this timeframe. Isometric strength was measured for the hip abductor muscles using a load cell force-detecting dynamometer (Lafayette Instruments, Lafayette, IN) secured via a strap against the youth athlete's leg. The specific test positions were as described by Ireland, Willson, Ballantyne, and Davis (2003). The youth athletes were instructed to push with maximal effort for 5 s, and this was repeated three times on each leg with a 15 s rest between trials. The strength tests were all conducted by a single physiotherapist, experienced in the use of the load cell force-detecting dynamometer. Within-session reliability for these tests using this device has been previously reported as moderate to good for all strength measures (Sheerin, Hume, Whatman, & Croft, 2010).

Descriptive statistics for demographic variables are represented as mean and standard deviations (SDs), and were calculated for control and experimental groups at pre- and post-intervention (see Table 1). Paired *t*-test statistics for the baseline variation between the experimental and control groups showed there were no significant differences ($p < 0.05$) between groups for age, height, body mass, or hip abductor muscle strength. To achieve balanced control and experimental groups, a form of minimisation was employed for hip abductor strength and frontal plane knee control (maximum stance phase knee abduction angle) (Treasure & MacRae, 1998) based on subsequent pairs in rank order from pre-intervention (baseline) testing results.

Table 1
Participant characteristics.

	Combined (n = 19; 11 M; 8 F)	Control (n = 11; 8 M; 3 F)	Intervention (n = 12; 4 M; 8 F)
Age (years)	11.5 ± 1.4	11.3 ± 1.7	11.6 ± 0.6
Height (m)	1.54 ± 0.10	1.53 ± 0.11	1.55 ± 0.10
Mass (kg)	43.7 ± 7.9	42.2 ± 9.0	45.0 ± 6.8

The data collection session was completed with the youth athletes undergoing a treadmill-based assessment of running gait kinematics. A nine-camera motion analysis system (Qualysis Medical, AB, Sweden) recorded lower body 3-dimensional (3D) kinematics at a sampling rate of 240 Hz. Twenty-one individual retro-reflective markers were secured to specific anatomical locations by an experienced physiotherapist. Two cluster marker sets were also attached to the thigh and shank of each leg (Whatman, Hing, & Hume, 2011) (Fig 1). Youth athletes ran for 5 min at a self-selected speed (mean ± SD: 2.19 ± 0.22 m/s). Bates, Dufek, and Davis (1992) suggested that a minimum of five trials are needed to achieve 90% power for sample sizes of at least ten participants. Therefore the youth athletes completed 30 s of running to achieve the required data set of ten running strides. Kinematic data were collected in two 30 s increments at 2-min intervals. Motion data were combined with participants' height and weight in Visual 3D (C-Motion Inc, USA) to create geometric objects of appropriate shape and mass to represent the pelvis, thigh, shank and foot body segments. Joints in the model were defined as places where the distal end of one segment met the proximal end of another segment, and analyses of joint motion was based solely on the relative motion between segments. Data from running files were filtered with a second-order Butterworth bidirectional low-pass filter with a cut-off frequency of 12 Hz. Kinematic data were exported as 'text' files and imported into Labview (National Instruments, USA) for further analysis. A customised Labview programme processed the lower limb kinematic data and output maximum and minimum joint angles during the loading response of stance phase of ten running strides. A standard error of measurement of 10% or less is considered small in pure test-repeats of three or more trials (Bennell, Crossley, Wrigley, & Nitschke, 1999). Our typical errors expressed as coefficient of variation percentages (CV%) were 10–13% indicating moderate variability for hip and knee ab/adduction between subjects. Reliability assessment for the gait variables presented in this paper was previously determined with average to good between-session reliability achieved (Sheerin, Whatman, Hume, & Croft, 2010).

All youth athletes in the LTAD programme completed either control or experimental exercises during the first 10 min of their normal training session for three mornings a week for eight weeks. The experimental group completed functional weight bearing exercises aimed at minimising knee valgus angle and open and closed kinetic chain exercises to promote hip muscle activation. These exercises were sourced from other studies (Hewett et al., 1999; Myer, Chu et al., 2008; Presswood et al., 2008). The exercises progressed in difficulty over the course of the intervention. A full description of each exercise is provided in Table 2. The control group completed a range of open and closed kinetic chain upper limb strengthening exercises including low pulley row and overhead pull-down with a resistance band, bicep curls, lying chest press, front and side shoulder raises, and overhead press with small

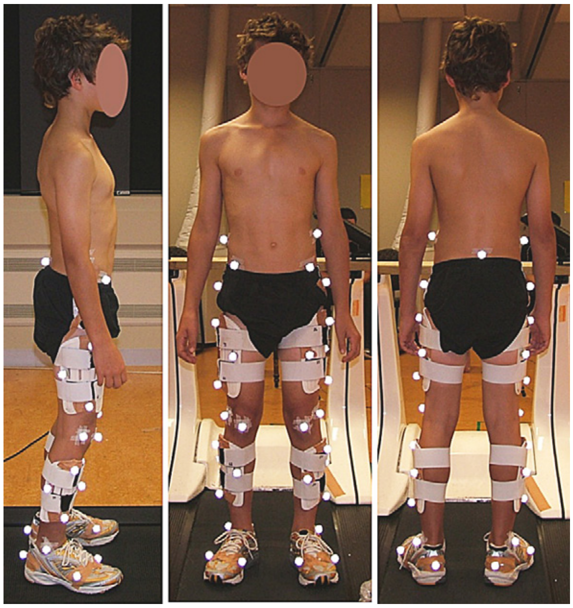

Fig. 1. Marker placements for running lower limb kinematic analysis.

hand-weights, in addition to tricep dips from a bench. Through the kinetic chain some upper limb exercises may have the potential to influence trunk stability and therefore lower limb control, however care was taken to choose exercises for the control group that would minimise this effect. Both the control and intervention exercises were supervised at all times by a qualified exercise professional. Individual technique correction was provided when required.

Descriptive statistics for all variables are represented as mean and standard deviations. The Hopkins (2009) spreadsheet for pre- and post-parallel groups analysis was used to provide estimates of the effect of the intervention on the youth athletes in the control and experimental groups. Qualitative inferential outcomes based on interpretation of the span of the confidence interval relative to magnitude thresholds for effects were calculated. Effect sizes were interpreted as trivial (0.0–0.1), small (0.11–0.3), moderate (0.31–0.5), large (0.51–0.7), very large (0.71–0.9), or extremely large (0.91–1.0) (Hopkins, Marshall, Batterham, & Hanin, 2009).

3. Results

The pre-intervention angles (i.e. baseline) were small for both groups (see Table 3), however there were some small left to right limb differences within the groups such as for hip adduction where the mean pre-intervention angle was 9.5 ± 1.4° and 6.0 ± 1.4° for the right and left sides respectively for the control group and 9.4 ± 2.0° and 5.2 ± 1.9° for the experimental group (see Table 3). The mean post-intervention angle was 9.1 ± 1.4° and 5.6 ± 1.4° for the right and left sides respectively for the control group and 9.4 ± 1.9° and 5.6 ± 1.5° for the experimental group. These changes equated to a small beneficial effect (effect size = 0.22) for the right hip and a trivial effect (effect size = 0.09) on the left. For knee abduction the mean pre-intervention angle was 6.5 ± 3.5° and 6.6 ± 4.0° for the right and left sides respectively for the control group and 7.1 ± 2.1° and 7.0 ± 1.4° for the experimental group. The mean post-intervention angle was 8.8 ± 3.1° and 5.7 ± 2.4° for the right and left sides respectively for the control group and 9.1 ± 3.0° and 8.0 ± 1.8° for the experimental group. These changes equated to a trivial effect (effect size = −0.3) for the right knee and a negative (very large) effect (effect size = 0.77) for the left.

Table 2
Descriptions of the exercises included in the lower limb functional exercise programme.

Exercise and source	Description
Side lying hip abduction (Presswood et al., 2008)	Athlete side lying with a resistance band tied around their knees. The top leg is abducted upwards against the band resistance, and slowly lowered to the starting position (progressed to three sets of ten repetitions).
Double leg squats (Presswood et al., 2008)	From standing, the athlete bends at the knees and hips into a crouched position. Some forward inclination of the trunk is permitted, however, the knees should not go into a varus or valgus position (progressed to three sets of ten repetitions).
Crab walking (Presswood et al., 2008)	With a resistance band tied around the athletes' ankles, in a slow movement, the athlete abducts one leg laterally as far as possible and places it back on the ground. The athlete then lifts their second leg and slowly brings it to meet the first. This pattern is repeated (progressed to two sets of 20 s).
Standing hip abduction (Presswood et al., 2008)	A resistance band is tied around a fixed structure. The athlete stands side on to the band and loops it around both feet. While maintaining an erect posture the athlete slides their foot out and slowly abducts their leg. Their leg is then slowly returned to the starting position and the pattern repeated (progressed to three sets of ten repetitions).
Single leg squat (Myer, Paterno, et al., 2008)	The athlete squats on a single leg, attempting to achieve approximately 90° knee flexion. When viewed anteriorly, the knee should remain above the ankle and below the hip at all times. This exercise was advanced by wrapping a resistance band around the knees of the athlete and having them hold it taut (progressed to three sets of ten repetitions).
Jump squats (Hewett et al., 1999)	As with 'double leg squats', however the athlete first jumps vertically, before landing into a squat position. The bottom position should be held for 5 s (progressed to five sets of three repetitions).
Jump squats with rotation (90° or 180°) (Hewett et al., 1999)	As with 'jump squats', however the athlete performs a 90° (180°) rotation in the air before landing in a squat position. The bottom position should be held for 5 s (progressed to five sets of three repetitions).
Broad jump (forward deep hold) (Myer, Paterno, et al., 2008)	The athlete begins in a semi-squat position and then jumps forward to achieve maximum distance. The athlete must stick the landing with their knees bent to approximately 90° and with no inwards collapse. This position should be held for 5 s and the knees should not go into a varus or valgus position (progressed to three sets of ten repetitions).
Broad jump (single leg) (Hewett et al., 1999)	The athlete begins in a semi-squat position and then jumps forward to achieve maximum distance and landing on one leg. The athlete must stick the landing with their knee bent to approximately 90° and with no inwards collapse. This position should be held for 5 s and the knees should not go into a varus or valgus position (progressed to three sets of ten repetitions).
Box drops (double leg landing) (Hewett et al., 1999)	The athlete drops down from a 30 cm high box, landing with both feet in the squat position (progressed to five sets of three repetitions).

Table 3
Pre- and post-intervention means, standard deviations, change in means, differences in changes in means and effect size for control versus experimental groups for hip and knee frontal plane angles.

	Right lower limb		Left lower limb	
	Control	Experimental	Control	Experimental
Hip				
Pre-intervention mean ± SD (degrees)	9.5 ± 1.4	9.4 ± 2.0	6.0 ± 1.5	5.2 ± 1.9
Post-intervention mean ± SD (degrees)	9.1 ± 1.4	9.4 ± 1.9	5.6 ± 1.5	4.9 ± 1.6
Change in means (pre-post intervention) (degrees)	0.4	0	0.4	0.3
Difference in change in means (control − experimental) (degrees)	0.4		0.1	
Effect size control vs. experimental (90% CI)	0.22 (−1.1 to 2.0)		0.09 (−0.9 to 1.2)	
Inference control vs. experimental	small beneficial		trivial	
Knee				
Pre-intervention mean ± SD	6.5 ± 3.5	7.1 ±2.1	6.6 ± 4.0	7.0 ± 1.4
Post-intervention mean ± SD	8.8 ± 3.1	9.1 ± 3.0	5.7 ± 2.4	8.0 ± 1.8
Change in means (pre-post intervention)	−2.3	−2.0	0.9	−1.0
Difference in change in means (control − experimental)	−0.3		1.9	
Effect size control vs. experimental (90% CI)	−0.08 (−3.4 to 2.9)		0.77 (0.1 to 3.7)	
Inference control vs. experimental	trivial		very large detrimental	

4. Discussion

The intervention programme employed with the experimental group consisted of a series of functional weight bearing exercises aimed at minimising knee valgus angle and open and closed kinetic chain exercises to promote hip muscle activation. However, there were minimal differences between pre- and post-intervention frontal plane hip and knee angles between the control and experimental groups, indicating that the intervention was not effective in improving the targeted gait measures in this cohort of youth athletes.

When the change in mean between the control and experimental groups was considered, no change, or a small change in either direction (to account for normal variation), was expected in the control group. The aim of the lower limb functional exercise programme was to reduce hip and knee frontal plane motion, and therefore it was expected that there would be a positive change in mean hip and knee frontal plane motion for the experimental group. The left hip was the only variable that demonstrated this change, but the magnitude of the effect was trivial. There was no consistent reduction in frontal plane angle for the right hip, or the knee on either side with the youth athletes who followed the functional lower limb exercise programme.

The left knee frontal plane angle demonstrated a very large negative effect. However, the difference in the change in means (1.9°) between the control and experimental group, pre- and post-intervention, was still within the variability demonstrated by the control group pre-intervention (6.6 ± 4.0°), and the whole group at baseline (6.8 ± 2.4°) (Sheerin, Whatman et al., 2010). This result can partially be explained by the natural movement variability demonstrated within youth athletes. The slow running speed selected by the participants may also help explain the small angles measured. Although the participants were familiarised with treadmill running, they were not necessarily familiar with the laboratory environment and this could have lead them to select a slow running speed resulting in small joint angles.

There are several potential reasons that could explain why no beneficial changes in frontal plane angles were measured during running. Firstly, some subjects may have exhibited normal angles at baseline, and therefore were not likely to have changed with intervention. Ideally subjects would have been compared with published norms at baseline, and those demonstrating normal angles would have been excluded from further intervention. However, no published normal values exist, and therefore this was not possible. The second potential reason for no demonstrated changes was the structure of the intervention programme. Although the duration of the intervention was considered appropriate based on other intervention studies with similar goals (Herman, Weinhold, Guskiewicz, Garrett, Yu, & Padua, 2008; Myer, Ford, Palumbo, & Hewett, 2005; Snyder, Earl, O'Connor, & Ebersole, 2009), the overall volume may have been too low. It would have been preferable to have the youth athletes carrying out the exercises five to six days a week. However, with the LTAD group only gathering on three days per week, and the need for close supervision of the exercises to ensure correct technique, this was not possible. There was also the potential that there wasn't direct cross-over between the intervention exercises and frontal plane control during running.

The exercises selected for the intervention would typically be employed clinically (Myer, Paterno, Ford, & Hewett, 2008), and are similar to those described in other studies (Presswood et al., 2008). Although the youth athletes who underwent the 8-week lower limb functional exercise intervention qualitatively showed improvements in their exercise technique and lower limb alignment (as observed by the researcher, but not assessed), there was no cross-over in terms of improvement to running mechanics.

This study was original in that it is the first to describe the effects of a lower limb functional exercise intervention aimed at changing running mechanics in a cohort of youth athletes. No research has previously been conducted with youth athletes specifically assessing the change in running technique, and therefore it was not possible to compare the findings from this study with a comparable group. Largely positive effects of similar lower limb functional exercise programmes have been demonstrated on lower limb running mechanics (Snyder et al., 2009), and the incidence of lower limb injuries (Heidt, Sweeterman, Carlonas, Traub, & Tekulve, 2000; Junge, Rösch, Peterson, Graf-Baumann, & Jiri Dvorak, 2002; Pasanen et al., 2008; Steffen, Myklebust, Olsen, Holme, & Bahr, 2008), in non-injured adult populations. However, there is no way of knowing if these findings are unique to adults, and whether children would respond in a similar manner.

Given the scarcity of research in this area, there is a need for further studies assessing the running mechanics of youth athletes. Gait measures could be a useful clinical screening tool, however, future research should continue to examine how these measures can be used for monitoring athletic movement development. There is also the need for appropriately designed, large-scale studies, to determine whether there are any sub-groups of youth athletes who would benefit more from lower limb functional training.

Future research should continue to define which exercises are best used with youth athletes, as well as to examine how assessment measures can be used for monitoring athletic movement development.

Please cite this article in press as: Sheerin, K. R., et al., Effects of a lower limb functional exercise programme aimed at minimising knee valgus angle on running kinematics in youth athletes, *Physical Therapy in Sport* (2012), doi:10.1016/j.ptsp.2012.01.003

5. Conclusions

Although the effect of the 8-week lower limb functional exercise programme employed on this occasion was minimal in changing frontal plane hip and knee motion when running, this study was the first to describe the effects of such an intervention on the running mechanics of youth athletes.

6. Practical implications

1. Include more volume for the lower limb functional exercise intervention to increase the likelihood of an effect on running mechanics.
2. Determine a series of lower limb functional exercises that are suitable for use with youth athletes.
3. Determine more sensitive assessment measures to help classify youth athletes with variable movement patterns.

Conflict of interest

Non-declared.

Ethical approval

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (Reference number: 08/258).

Funding

Financial support for this study was provided by Sport and Recreation New Zealand (SPARC).

Acknowledgements

The authors would like to thank Sport and Recreation New Zealand for their financial support of this project. Thanks are also given to the Millennium Institute of Sport and Health LTAD programme leader Cesar Meylan for his cooperation in making this project a success, to the LTAD athletes who participated in the project, Professor Will Hopkins for his statistical advise, and Rodrigo Bini for his assistance with data processing.

References

Adirim, T., & Cheng, T. (2003). Overview of injuries in the young athlete. *Sports Medicine, 33*(1), 75.

Bates, B., Dufek, J., & Davis, H. (1992). The effect of trial size on statistical power. *Medicine and Science in Sports and Exercise, 24*(9), 1059–1065.

Bennell, K., Crossley, K., Wrigley, T., & Nitschke, J. (1999). Test-retest reliability of selected ground reaction force parameters and their symmetry during running. *Journal of Applied Biomechanics, 15*, 330–336.

Ferber, R., Davis, I., Hamill, J., Pollard, C., & McKeown, K. (2002). Kinetic variables in subjects with previous lower extremity stress fractures. *Medicine and Science in Sports and Exercise, 34*(5), S5.

Ferber, R., Noehren, B., Hamill, J., & Davis, I. (2010). Competitive female runners with a history of iliotibial band syndrome demonstrate atypical hip and knee kinematics. *Journal of Orthopaedic and Sports Physical Therapy, 40*(2), 52–58.

Heidt, R., Sweeterman, L., Carlonas, R., Traub, J., & Tekulve, F. (2000). Avoidance of soccer injuries with preseason conditioning. *American Journal of Sports Medicine, 28*, 659–662.

Herman, D., Weinhold, P., Guskiewicz, K., Garrett, W., Yu, B., & Padua, D. (2008). The effects of strength training on the lower extremity biomechanics of female recreational athletes during a stop-jump task. *American Journal of Sports Medicine, 36*(4), 733–740.

Hewett, T., Ford, K., & Myer, G. (2006). Anterior cruciate ligament injuries in female athletes. Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *American Journal of Sports Medicine, 34*(3), 498.

Hewett, T., Lindenfeld, T., Riccobene, J., & Noyes, F. (1999). The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *American Journal Of Sports Medicine, 27*(6), 699–706.

Hewett, T., Myer, G., Ford, K., Heidt, R., Colosimo, A., & McLean, S. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *American Journal of Sports Medicine, 33*(4), 492–501.

Hopkins, W. (2009). *Spreadsheet for the analysis of reliability (beta version)*. Retrieved 2010, from. http://www.sportsci.org/.

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sport and Exercise, 41*(1), 3–12.

Ireland, M., Willson, J., Ballantyne, B., & Davis, I. (2003). Hip strength in females with and without patellofemoral pain. *Journal Of Orthopaedic And Sports Physical Therapy, 33*(11), 671–676.

Junge, A., Rösch, D., Peterson, L., Graf-Baumann, T., & Jiri Dvorak, J. (2002). Prevention of soccer injuries: a prospective intervention study in youth amateur player. *American Journal of Sports Medicine, 30*(5), 652–659.

Mann, R., Moran, G., & Dougherty, S. (1986). Comparative electromyography of the lower extremity in jogging, running, and sprinting. *American Journal of Sports Medicine, 14*, 501–509.

Micheli, L., Glassman, R., & Klein, M. (2000). The prevention of sports injuries in children. *Clinics in Sports Medicine, 19*(4), 821–834.

Milner, C., Hamill, J., & Davis, I. (2010). Distinct hip and rear foot kinematics in female runners with a history of tibial stress fracture. *Journal of Orthopaedic and Sports Physical Therapy, 40*(2), 59–66.

Myer, G., Chu, D., Brent, J., & Hewett, T. (2008). Trunk and hip control neuromuscular training for the prevention of knee joint injury. *Clinics in Sports Medicine, 27*, 428–448.

Myer, G., Ford, K., Palumbo, J., & Hewett, T. (2005). Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *National Strength and Conditioning Association, 19*(1), 51–60.

Myer, G., Paterno, M., Ford, K., & Hewett, T. (2008). Neuromuscular training techniques to target deficits before return to sport after anterior cruciate ligament reconstruction. *Journal of Strength and Conditioning Research, 22*(3), 987–1014.

Pasanen, K., Parkkari, J., Pasanen, M., Hiilloskorpi, H., Makinen, T., Jarvinen, M., & et al. (2008). Neuromuscular training and the risk of leg injuries in female floorball players: cluster randomised controlled study. *British Medical Journal, 337*(10), 802–805.

Powers, C. (2010). The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. *Journal of Orthopaedic and Sports Physical Therapy, 40*(2), 42–51.

Presswood, L., Cronin, J., Keogh, J., & Whatman, C. (2008). Gluteus medius: applied anatomy, dysfunction, assessment, and progressive strengthening. *Strength and Conditioning Journal, 30*(5), 41–53.

Seto, C., Statuta, S., & Solari, I. (2010). Pediatric running injuries. *Clinics in Sports Medicine, 29*, 499–511.

Shanmugam, C., & Maffulli, N. (2008). Sports injuries in children. *British Medical Bulletin, 86*(1), 33–57.

Sheerin, K. R., Hume, P. A., Whatman, C., & Croft, J. (2010). Reliability of lower limb strength, flexibility and 3D gait measures during running in young athletes. Symposium conducted at the meeting of the Sports Medicine New Zealand Conference, Wellington, New Zealand.

Sheerin, K., Whatman, C., Hume, P. A., & Croft, J. (2010). *Reliability of 3D gait kinematics in treadmill running in healthy young athletes*. Presented at the meeting of the International Society of Biomechanics in Sports Congress, Michigan, USA.

Snyder, K., Earl, J., O'Connor, K., & Ebersole, K. (2009). Resistance training is accompanied by increases in hip strength and changes in lower extremity biomechanics during running. *Clinical Biomechanics, 24*, 26–34.

Steffen, K., Myklebust, G., Olsen, O., Holme, I., & Bahr, R. (2008). Preventing injuries in female youth football – a cluster-randomized controlled trial. *Scandinavian Journal of Medicine and Science in Sports, 18*(5), 605–614.

Stein, C., & Micheli, L. (2010). Overuse injuries in youth sports. *The Physician and Sportsmedicine, 38*(2), 102–108.

Treasure, T., & MacRae, K. (1998). Minimisation: the platinum standard for trials? Randomisation doesn't guarantee similarity of groups; minimisation does. *British Medical Journal, 317*, 362–363.

Whatman, C., Hing, W., & Hume, P. (2011). Kinematics during lower extremity functional screening tests—are they reliable and related to jogging? *Physical Therapy in Sport, 12*, 22–29.