The effects of complex training on neuromuscular development of the lower limbs in youth netball players

Benjamin R. Humphrys, Rodrigo Aspe, Richard Clarke & Jonathan D. Hughes

Exercise and Sport Research Center, University of Gloucestershire, United Kingdom

Corresponding author.

Benjamin R. Humphrys

University of Gloucestershire
Oxstalls Campus
Oxstalls Lane
Gloucester
GL2 9HW

E-mail address: ben.humphryspt@hotmail.co.uk

The Effects of Complex Training on Neuromuscular Development of the Lower Limbs in Youth Netball Players

Abstract

Objective: The high prevalence of injury in netball can be associated with intrinsic or extrinsic factors. Female athletes have an increased risk of injury as they enter into maturity due to increased joint laxity and a reduction in neuromuscular control, resulting in altered landing biomechanics and greater knee joint injury risk. This study sought to investigate whether complex training (CT) could improve neuromuscular strength and landing kinematics, thereby reducing injury risk to the knee.

Methods: A within subject, repeated measures design was utilised. Ten youth netball academy players (age, 15.3 ± 0.9, years; height, 169.0 ± 7.0, cm; body mass, 62.2 ± 6.9, kg) participated and attended one familiarisation and two testing sessions (pre- and post-intervention). Participants' were assessed on: countermovement jump (CMJ), landing error score system (LESS), and single leg countermovement jump (SLCMJ) of both limbs. All participants engaged in a 6 week, one day per week, strength training and plyometric intervention for the lower limbs utilising CT.

Results: Significant improvements were evidenced for CMJ height ($p = 0.001$, $d = 1.2$ "moderate" effect), CMJ peak power output (PPO) ($p = 0.001$, $d = 0.7$ "small" effect), LESS ($p = 0.002$, $d = 1.7$ "large" effect), and SLCMJ left height ($p = 0.01$, $d = 1.2$ "moderate" effect) following the intervention.

Conclusion: Performing one CT session a week over 6 weeks enhanced kinematics and performance of jumping activities both bilaterally and unilaterally, it also brought about reductions in asymmetries in young female athletes.

Keywords: Injury; Reduction; Risk; Prevention; Power; Plyometric; Strength; Training

Introduction

Elite netball is a sport that carries both intrinsic (athlete dependant) and extrinsic (environment dependant) factors that could increase the risk potential for injury [1]. The effectiveness of training programmes to decrease injury risk has been studied within many adolescent sports e.g. soccer, basketball and volleyball [2]. Therefore, it is paramount that adolescent netball players undertake physical preparation training to protect against injury as well as enhance performance.

The rules in netball require players to come to a complete stop within one-and-a-half steps of receiving the ball. Players have been observed to adopt various movement strategies when receiving the ball including; a hop or leap onto one foot or a horizontal jump landing on both feet [3]. Netball players are reported to land unilaterally 65% and bilaterally 35% of the time [4]. These data signify an increased risk for injury when landing unilaterally due to the decreased base of support, reduced stability, high ground reaction forces (GRF) and potential increase in muscle activation creating more of an abrupt landing. With impact forces upon landing reported to be around 6.8 times body weight [5] guidance on optimal landing strategies is of high importance as well as appropriate neuromuscular training in order for players to withstand and absorb the force. Successful netball performance is therefore dependant on qualities that are both forceful and explosive, requiring high levels of muscular strength and power production. Therefore, training must look to develop lower limb strength, control and the full range of movement patterns, as well as netball and position specific landing strategies to reduce the potential risk for injury and ultimately enhance physical performance.

Data from national league competition in Australia, has reported injury rates ranging between 66.7 and 71.4 per 1000 participations over three seasons [6]. The predominant type of injuries being ligamentous and are sustained in competition rather than training [6]. Anterior-cruciate ligament (ACL) injuries are particularly traumatic as a typical return to play time can take 6-9 months depending on the severity of the injury [7]. Specifically, for netball athletes, the type of ACL injury that occurs is non-contact during landing and change of direction tasks through having to decelerate combined with change of direction executed with the foot planted [7] which is typically executed in an upright stance [8], potentially reducing hamstring activity and protective posterior pull on the tibia. Strategies for reducing non-contact ACL injuries could be lower limb resistance strength training. As highlighted, females typically land and change direction with an erect trunk position [8] with minimal knee flexion [9] which may in part be due to early quadriceps activation or delayed hamstrings activation [10]. If the co-activation of the quadriceps and hamstring muscles is enhanced, then this may act as an injury protective mechanism during landing by resisting anterior and lateral tibial translation along with transverse tibial rotations [11]. Greater activation and strength, of the hamstring muscles will allow the knee to produce greater knee flexion angles [12], resulting in a safer and more advantageous position to absorb the high impact forces experienced.

Descriptive epidemiological data identified the knee joint as having a high risk of injury recurrence potentially explained via, limb asymmetry (intrinsic factor) or due to the demands of high level competition, playing surface and footwear (extrinsic factors) [13]. Asymmetry between limbs is widely used to quantify functional deficit and as such can be linked to an increased chance of injury and impaired sports performance [14]. An asymmetry value of 10-15% between limbs has been proposed as the threshold where the incidence for injury may be highest [15]. To improve neuromuscular strength, symmetry and control of the lower limbs, strength training interventions utilising complex training (CT) have been employed [16]. CT involves the execution of a resistance-training exercise using a heavy load (1–5RM) followed relatively quickly by the execution of a biomechanically similar plyometric exercise [17]. This form of training has been associated with the enhancement of jump performance [18,19] and power output [17,19] based on the premise that the explosive capability of a muscle is enhanced after it has just been subjected to maximal or near-maximal contractions.

The aims of the present study therefore, were to implement a strength training intervention targeted at improving neuromuscular strength and control of the lower limbs utilising CT and further, to assess if the potential injury risk when landing can be reduced through the intervention and landing skills instruction.

Methods

Design and Participants

A within subjects, repeated measures design was conducted. Data was collected on ten youth netball players (mean ± SD: age: 15.3 ± 0.9 years; stature 169.0 ± 7.0 cm; mass: 62.2 ± 6.9 kg; maturity offset: 0.2 ± 0.6 years). Fourteen youth netball academy players agreed to participate in the investigation; however, 4 participants were excluded from analysis due to the 80% minimum attendance rating. Prior to initial data collection, participants undertook a familiarisation session for the CMJ tests, but not for the LESS tests as practice attempts may have caused the participants to learn superior landing techniques, thus interfering with potential results. Written informed consent was obtained from participants' and their parents/guardians who had been approved by the University's Research Ethics Committee.

Methodology

Anthropometry

Standing and sitting height was measured to the nearest mm using a stadiometer (Holtain Limited, Crymych). Leg length was calculated from standing height minus sitting height. Participant's exact age was calculated using their date of birth and the date of baseline testing. Maturation as determined by age from peak height velocity (APHV) was done using known equations [20].

Countermovement jumps

Participants performed 3 CMJs followed by 3 SLCMJs on their right leg then left leg with 10 seconds of rest between attempts and 3 minutes between tests. All jumps were performed using a linear position transducer (GymAware, Kinetic Performance Technology, and Canberra, Australia). The tether was attached to the right-hand side of a wooden dowel rod resting on the participant's shoulders. The participants were instructed to self-select their depth for CMJ performance. For SLCMJ participants were told to initiate the jump from standing on one leg while keeping their free leg fixed. The free leg was positioned in front of the body with 20-30^0 of hip flexion to avoid any momentum being created through the jump; participants proceeded to land on the same leg. The averages of three jumps were taken for analysis for both CMJ and SLCMJ [21].

PPO for both jumps was calculated as:

$$PPO\ (w) = 60.7 \times \text{jump height (cm)} + 45.3 \times \text{body mass (kg)} - 2055$$

[22]

Limb symmetry index (LSI). Limb dominance was defined as the limb the participant would use to kick a ball [23]. The LSI was determined as:

$$= (\text{Non-dominant} - \text{dominant}) / \text{dominant} \times 100$$

[24]

An LSI of >85% was considered to be within the normal range of limb symmetry [15]. The symmetry index score (SIS) was the percentage of participants exhibiting >15% of limb asymmetry.

Landing error score system

For the LESS test, participants performed a double-leg horizontal jump from a 30cm box, landing out in front of the box with both feet at a distance of approximately half their body height, marked by a line on the ground and then immediately jumping upwards as high as possible. Participants were given verbal instruction on the task and were allowed one practice jump before the three jump trials were recorded. If the participant did not jump to the required horizontal distance or did not vertically jump after the initial landing, the trial was discarded, and the jump-landing manoeuvre repeated [25].

Two tripod-mounted digital camcorders Kodak PlaySport Zx5 (Eastman Kodak Company, Rochester, New York, USA) recorded frontal and sagittal views of each jump [25], at a distance of 5m each. All jump-landing videos were analysed at a later time using (QuickTime; Apple Inc, Version 10.4 (833.7), Cupertino, CA). Scoring is based on the presence or absence of specific landing characteristics. Individually scored items are totalled to create an overall LESS score (range 0-17), with higher scores indicating higher-risk landing technique. Overall LESS scores were averaged over three jump trials for analyses.

Training intervention

Following initial testing participants undertook the strength training intervention for a total of 6 weeks (Table 1). The intervention was one day per week using CT methods focusing on predominately bilateral exercises as well as the inclusion of a unilateral strength exercise and plyometrics which was implemented during the warm up and main body of the session. The training intervention occurred on the same day at the same time every week and was delivered by the same strength and conditioning coach at every session.

Table 1 Warm up and training intervention programme

Training Intervention (Sets / Reps) prescription			
Warm up			
	Exercise	**Sets/Reps**	**Rest (sec)**
Week 1 - 6	1A: Spiderman with reach	1 x 6 e/s	n/a
	1B: Pigeon	1 x 6 e/s	
	1C: Squat to stand	1 x 8	
	1D: Single leg glute bridge	1 x 8 e/s	
	1E: Side plank with hip flexion & extension	1 x 6 e/s	
	1F: Lateral box step ups	1 x 6 e/s	
	2A: Double leg pogos	2 x 12	30 - 60
Week 1 - 2	3A: Broad jump & stick	2 x 3	60
Week 3 - 4	3A: 2 Repeated broad jumps	2 x 2	60
Week 5 - 6	3A: 2 Repeated broad jumps into maximal vertical jump	2 x 2	60

Note: Each last rep stuck for 3 seconds for exercises 3A.

Abbreviations: E/S = Each side.

Exercise	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**
1a) BB paused front squat	3 x 8	4 x 6	4 x 5	4 x 4	4 x 4	5 x 3
1b) Bilateral box jumps	3 x 3	4 x 3	4 x 4	4 x 5	4 x 6	5 x 5
2a) BB Romanian deadlift	3 x 8	4 x 6	4 x 5	4 x 4	4 x 4	4 x 3
2b) Drop jump 30cm box	3 x 3	4 x 3	4 x 4	4 x 5	4 x 6	4 x 6
3a) DB RFE split squat with contralateral loading	3 x 8 E/L	3 x 6 E/L	3 x 5 E/L	2 x 6 E/L	3 x 5 E/L	2 x 5 E/L
3b) Supine row	3 x 5-8	3 x 5-8	4 x 5-8	4 x 5-8	3 x 4-6*	3 x 5-8*

Note: Rest periods ranged from 90 seconds to 150 seconds as the weeks progressed.

Abbreviations: E/L = Each leg, BB = Barbell, DB = Dumbbell, RFE = rear foot elevated, * = feet elevated.

Statistical Analyses

Data are presented as mean ±*SD*. All data was tested for normality using the Shapiro-Wilks test. Multiple one-way repeated measures ANOVA's were conducted; if significance was found, post hoc analysis was applied using the Bonferroni correction. The magnitude of the effect of the intervention was also calculated using effect size (ES) statistics via Cohen's *d*; the magnitude of change was interpreted from Rhea's scale of effect size classification [26], participants were categorised as recreationally trained. For all statistical analyses, the level of significance was set at $p \leq 0.05$.

Results

All variables were normally distributed. Statistical significance was found between pre-and post-measures of CMJ height, CMJ PPO, SLCMJ L height, SLCMJ L PPO and LESS ($p < 0.05$) (Table 2). There was no significant difference between SLCMJ L and R height or PPO pre- or post-intervention ($p > 0.05$). The change in asymmetry between pre-and post-intervention is displayed in (Table 3). Limb asymmetries were reduced by 73.3% in SLCMJ post intervention, whilst reducing the SIS by 10% (Table 3). Within session coefficient of variation pre-to-post-intervention identified high reliability for CMJ (5.4 – 4.5%) and lower reliability for SLCMJ R (9.6 – 7.0%) and SLCMJ L (10.2 – 7.6%). Similarly, between session reliability for CMJ (ICC =0.81) was high and SLCMJ R (ICC = 0.74) and SLCMJ L (ICC = 0.57) were less reliable.

Table 2 Pre and post intervention results for physical tests (mean ± *SD*) *n* = 10

	Mean ± *SD*					
	Pre	**Post**	**% Change**	**p value**	**ES**	**Magnitude**
CMJ (cm)	31.3 ± 3.3	35.8 ± 3.9	14.4	0.001*	1.2	Moderate
SLCMJ R (cm)	21.3 ± 3.7	24.2 ± 4.8	13.6	0.105	0.7	Small
SLCMJ L (cm)	20.1 ± 2.7	24.5 ± 4.5	21.9	0.018*	1.2	Moderate
CMJ PPO (w)	2661.2 ± 401.6	2977.3 ± 443.6	11.9	0.001*	0.7	Small
SLCMJ R PPO (w)	2050.7 ± 406.8	2275.6 ± 536.2	11.0	0.057	0.5	Small
SLCMJ L PPO (w)	1980.3 ± 296.3	2292.2 ± 515.1	15.8	0.010*	0.7	Small
LESS	5.5 ± 2.3	2.4 ± 1.0	56.4	0.002*	1.7	Large
D SLCMJ (cm)	21.3 ± 3.7	24.5 ± 4.5	15.0	0.071	0.8	Small
ND SLCMJ (cm)	20.0 ± 2.7	24.1 ± 4.8	20.5	0.031*	1.1	Moderate
LSI (%)	87.7 ± 9.3	90.6 ± 5.9	3.31	0.499	0.4	Small

Note: *Significant difference between pre- and post-training measures.

Abbreviations: CMJ, countermovement jump; SL, single leg; PPO, peak power output; LESS, landing error score system; D, dominant; ND, non-dominant; LSI, limb symmetry index.

Table 3 Percentage and number of participants with limb asymmetry >15% and % change in dominant vs non-dominant jump height pre and post intervention

	Pre	**Post**	**% Change**
% SIS	3 (30%)	2 (20%)	10
% Change dom vs non-dom (*n* = 10)	-6.0	-1.6	-

73.3 Abbreviations: SIS, symmetry index score; dom, dominant; non-dom, non-dominant.

Discussion

The results demonstrate that CT significantly enhanced neuromuscular control through improving jump performance (CMJ & SLCMJ L), landing biomechanics (LESS) and PPO (CMJ & SLCMJ L) (Table 2). Furthermore, CT demonstrated a reduction in asymmetry between dominant and non-dominant jump height. To the authors best knowledge, a CT method has not yet been introduced into a training intervention aiming to improve neuromuscular control of the lower extremities. Typical neuromuscular interventions are based around developing proprioception, neuromuscular control, and flexibility, jumping and landing skills, strength, and balance, as these parameters are mostly associated with sports injury risk [27] and are considered to be related to intrinsic injury risk factors.

Previous research has demonstrated that CT produces similar results to regular resistance and plyometric training; however, CT offers greater practicality to the everyday strength coach for enhancing the aforementioned physical qualities in chronic conditions [18,19]. Both studies compared CT to a differing experimental group of resistance training, plyometric training and compound training on vertical jump height and power output. It was concluded from both studies that CT produced similar results to all other experimental training methods and thus was recommended as a viable training tool as similar improvements were found without any detriment to performance. In addition, CT allows for the incorporation of various modalities into one session offering variable and time efficient training. However, it must be noted that the populations used were both college age males and females, training multiple times per week, with no reference to training status, which may have implications on inferring these results to studies of differing populations.

Therefore, it is clear that the results from the present study are consistent with those highlighted from the current body of literature [18,19]. However, unlike both these studies, the current study did not utilise a differing group, whether that be a control or another experimental group to compare the effects of the CT intervention on the aforementioned measures, highlighting an area for future research design.

Since the present study has proposed an alternative method for enhancing neuromuscular development and control of the lower extremities through the use of CT and not traditional neuromuscular training to prevent lower limb injury risks, it is necessary to review the literature on neuromuscular training programmes targeted at injury prevention. Myer and colleagues [2] implemented a 6 week, 3 days a week training intervention that covered a multitude of components; plyometrics, movement training, core strengthening, balance training, resistance training and speed interval training. The authors saw significant improvements in measures of vertical jump, single-leg hop distance, speed, bench press 1RM, squat 1RM, knee ROM, and knee varus and valgus torques compared with their pre-trained values and with an untrained control group. The population examined in the study were very similar to the present study's participants, female athletes with a mean age of 15 and participating in team sports similar to netball. However, the training status of the athletes was not mentioned, which is critical when deciding if the training intervention employed can in fact be used as a viable training tool in trained athletes. Nevertheless, the present study's results are coherent with those found in Myer and colleagues [2]. The present study managed to see improvements with only one training session a week as opposed to three, possibly indicating that CT may be a superior method of enhancing the comparable measures of performance between studies and, offering strength coaches an alternative time efficient method of achieving similar results.

In addition, Hewett and colleagues [28] conducted a 6 week, 3 days a week training programme to see the effects of neuromuscular training on the incidence of knee injuries in females competing in high-risk sports. The results demonstrated that technique-oriented plyometrics with supplemental resistance training significantly reduced serious knee injuries, including ACL injuries, in adolescent volleyball, soccer, and basketball players. One potential drawback to the study was again, no mention of training status which has already been highlighted as critical in deciding if the training intervention can be applied to other populations. Furthermore, this study only looked at the effects of neuromuscular training on reducing injury risk, not measures of athletic performance. However, it can be speculated that with the amount of plyometric training that the participants underwent it is logical to assume that physical performance parameters like vertical jump performance would have improved.

Aside from focusing on neuromuscular development, much attention was given to jumping and landing mechanics during the intervention so that sound, safe technique was developed. Guidance was given on proper knee alignment, soft landings and deep knee flexion landings to reduce GRF. No kinetic measures were taken in the present study, however, when assessing the LESS test, participants exhibited substantial improvements from pre- to post-intervention testing ($p = 0.002$) showing a considerable improvement in landing biomechanics. These findings are similar to previous literature [2] where landing mechanics were also emphasised. Even though the present study witnessed dramatic improvements in landing kinematics, future research is advised to measure kinetic variables like GRF from the LESS test to determine if such an intervention can affect both the kinematics and kinetics of landing although, by doing so, will transform the LESS test from a field-based assessment tool, to one requiring laboratory testing procedures. However, this may prove to be potentially problematic if using large sample sizes as this would be impractical in time and expense. Therefore, the strength coach must decide which measures are most important to them.

The presence of a unilateral exercise in the intervention was two-fold; to develop single leg strength, postural control and balance, whilst possibly reducing any asymmetries found between dominant and non-dominant limbs thus encompassing more of the parameters found in neuromuscular training interventions associated with sports injury risk. As a result of its inclusion we successfully managed to reduce the asymmetry found in SLCMJ between dominant and non-dominant limbs post intervention by 73.3%, whilst reducing the SIS by 10% (Table 3).

However, these findings were surprising due to the low amount of single leg volume in comparison to bilateral volume although a potential explanation may be found in the CV and ICC values produced. Typically, we require CV values to be ≤ 5% for fitness testing in order for the results to be deemed reliable [29] and ICC values to be as close to 1.00 for highest reliability. Furthermore, it has been recommended that any measure should have an intra-class correlation coefficient of at least 0.6 to be useful [30]. Therefore, when analysing the present study's reliability values, we can conclude that there was too much variability of measurement error which may have interfered with the SLCMJ results, thus leading to a potential limitation within the study. To combat this, we recommend future researchers implement a longer familiarisation period to reduce the variance of scores between attempts as participants would then become more accustomed to the testing procedure. There are limitations to this study that must be considered. The relative sample of population for this group of athletes limited the opportunity to run an adequate control group to make full inferences on the intervention programme. Further, the number of participants that were recruited were low and this again may bias the findings. However, this is a first study into the role that CT may play in performance improvements and reduction of injury risk in youth female athletes.

Practical Applications

- Female athletes who participate in a 6-week neuromuscular training intervention can experience performance enhancement and significant improvements in movement biomechanics.
- Utilisation of CT as opposed to typical neuromuscular training interventions can act as a viable and useful method to enhance athletic capabilities and reduce potential injury risks specific to the investigated population.
- CT may serve as an alternative method of training for strength coaches who have limited time with their athletes who wish to develop multiple parameters at once whilst aiming to maintain athletic robustness throughout the competitive season.

Conclusion

The present study wanted to investigate whether CT could be an effective form of training to develop neuromuscular control and reduce injury risks in youth netball players as current research had not yet directly implemented this form of training into injury prevention studies. Our results demonstrate significant improvements in vertical jump performance, landing biomechanics, PPO and asymmetry between lower limbs following a 6-week CT protocol utilising heavy resistance strength exercises and plyometrics. Furthermore, due to the enhancement of neuromuscular control of the lower extremities, improved landing biomechanics and reduction in asymmetry, we can conclude that the training intervention reduced the potential risk for injury in female youth athletes which are associated with intrinsic injury risk factors. We recommend that future researchers look at comparing CT against a typical neuromuscular training programme on reduction of injury risk as well as athletic measures of performance. Furthermore, we advocate measuring leg stiffness and strength capabilities in addition to the aforementioned measures used in the present study, as we speculate strength and stiffness outcomes are to be seen with an enhancement of jump performance and landing biomechanics due to the underlying physiological mechanisms shared between these variables.

References

1. van Mechelen W, Hlobil H, Kemper HC (1992) Incidence, severity, aetiology and prevention of sports injuries. Sports Med 14(2): 82-99. PubMed
2. Myer GD, Ford KR, Palumbo OP, Hewett TE (2005) Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. J Strength Cond Res 19(1): 51-60. PubMed doi: 10.1519/13643.1
3. Hopper DM, Lo SK, Kirkham C, Elliot B (1992) Landing patterns in netball: Analysis of an international game. Br J Sports Med 26(2): 101-106. PubMed
4. Weinhandl JT, Joshi M, O'Connor KM (2010) Gender comparisons between unilateral and bilateral landings. J Appl Biomech 26(4): 444-453. PubMed
5. Hopper DM, McNair P, Elliott BC (1999) Landing in netball: Effects of taping and bracing the ankle. Br J Sports Med 33(6): 409-413. PubMed
6. Saunders N, Otago L (2009) Elite netball injury surveillance: Implications for injury prevention. J Sci Med Sport 12: S63. PubMed doi: https://doi.org/10.1016/j.jsams.2008.12.148
7. Silvers HJ, Mandelbaum BR (2007) Prevention of anterior cruciate ligament injury in the female athlete. Br J Sports Med 41: (suppl 1), i52-i59. PubMed doi: 10.1136/bjsm.2007.037200
8. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM (2004) Core stability measures as risk factors for lower extremity injury in athletes. Med Sci Sports Exerc 36(6): 926-934. PubMed
9. Blackburn JT, Padua DA (2008) Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing. Clin Biomech (Bristol, Avon) 23(3): 313-319.PubMed doi: 10.1016/j.clinbiomech.2007.10.003
10. Myer GD, Ford KR, Foss KDB, Liu C, Nick TG, et al. (2009) The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. Clin J Sport Med 19(1): 3-8. PubMed doi: 10.1097/JSM.0b013e318190bddb
11. Cibulka MT, Threlkeld-Watkins J (2005) Patellofemoral pain and asymmetrical hip rotation. Phys Ther 85(11): 1201-1207. PubMed

12. Hewett TE, Ford KR, Hoogenboom BJ, Myer GD (2010) Understanding and preventing ACL injuries: Current biomechanical and epidemiologic considerations-update 2010. N Am J Sports Phys Ther 5(4): 234. PubMed

13. Swenson DM, Yard EE, Fields SK, Comstock RD (2009) Patterns of recurrent injuries among US high school athletes, 2005–2008. Am J Sports Med 37(8): 1586-1593. PubMed doi: 10.1177/0363546509332500

14. Paterno MV, Myer GD, Ford KR, Hewett TE (2004) Neuromuscular training improves single-limb stability in young female athletes. J Orthop Sports Phys Ther 34(6): 305-316. PubMed doi: 10.2519/jospt.2004.34.6.305

15. Noyes FR, Barber SD, Mangine RE (1991) Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. Am J Sports Med 19(5): 513-518. PubMed doi: 10.1177/036354659101900518

16. Santos EJ, Janeira MA (2008) Effects of complex training on explosive strength in adolescent male basketball players. J Strength Cond Res 22(3): 903-909. PubMed doi: 10.1519/JSC.0b013e31816a59f2

17. French DN, Kraemer WJ, Cooke CB (2003) Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. J Strength Cond Res 17(4): 678-685. PubMed

18. MacDonald CJ, Lamont HS, Garner JC (2011) The Effects of 3 different modes of training upon measures of CMVJ performance. J Strength Cond Res 25: S7. doi: 10.1097/01.JSC.0000395590.02241.4a

19. Mihalik JP, Libby JJ, Battaglini CL, McMurray RG (2008) Comparing short-term complex and compound training programs on vertical jump height and power output. J Strength Cond Res 22(1): 47- 53. PubMed doi: 10.1519/JSC.0b013e31815eee9e

20. Mirwald RL, Baxter-Jones AD, Bailey DA, Beunen GP (2002) An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc 34(4): 689-694. PubMed

21. Markovic G, Dizdar D, Jukic I, Cardinale M (2004) Reliability and factorial validity of squat and countermovement jump tests. J Strength Cond Res 18(3): 551-555. PubMed doi: 10.1519/1533-4287(2004)18<551:RAFVOS>2.0.CO;2

22. Sayers SP, Harackiewicz DV, Harman EA, Frykman PA, Rosenstein MT (1999) Cross-validation of three jump power equations. Med Sci Sports Exerc 31(4): 572-577. PubMed

23. Ceroni D, Martin XE, Delhumeau C, Farpour-Lambert NJ (2012) Bilateral and gender differences during single-legged vertical jump performance in healthy teenagers. J Strength Cond Res 26(2): 452- 457. PubMed doi: 10.1519/JSC.0b013e31822600c9

24. Barber SD, Noyes FR, Mangine RE, McCloskey JW, Hartman W (1990) Quantitative assessment of functional limitations in normal and anterior cruciate ligament-deficient knees. Clin Orthop Relat Res 255: 204-214. PubMed

25. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE Jr, et al. (2009) The landing error scoring system (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. Am J Sports Med 37(10): 1996-2002. PubMed doi:10.1177/0363546509343200

26. Rhea MR (2004) Determining the magnitude of treatment effects in strength training research through the use of the effect size. J Strength Cond Res 18(4): 918-920. PubMed doi: 10.1519/14403.1

27. Emery CA, Cassidy JD, Klassen TP, Rosychuk RJ, Rowe BH (2005) Effectiveness of a home-based balance-training program in reducing sports-related injuries among healthy adolescents: A cluster randomized controlled trial. CMAJ 172(6): 749-754. PubMed doi: 10.1503/cmaj.1040805

28. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR (1999) The effect of neuromuscular training on the incidence of knee injury in female athletes: A prospective study. Am J Sports Med 27(6): 699-706. PubMed doi: 10.1177/03635465990270060301

29. Turner A, Brazier J, Bishop C, Chavda S, Cree J, et al. (2015) Data analysis for strength and conditioning coaches: Using excel to analyze reliability, differences, and relationships. Strength Cond J 37(1): 76-83. doi: 10.1519/SSC.0000000000000113

30. Chinn S (1991) Statistics in respiratory medicine 2. Repeatability and method comparison. J Thorac Imaging 46(6): 454-456. PubMed