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THE EFFECTS OF CHRONOLOGICAL AGE AND STAGE OF MATURATION ON LANDING KINEMATICS IN ELITE MALE YOUTH SOCCER PLAYERS

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ABSTRACT

Context: Despite the high frequency of knee injuries, there is a paucity of research to show the effects of chronological age and stage of maturation on knee joint kinematics in male youth soccer players.

Objective: To employ a 'coach friendly' screening tool to examine knee valgus scores for players of different ages and stage of maturation.

Design: Cross sectional study

Setting: Academy soccer clubs

Patients or other participants: 400 elite male youth soccer players aged between 10-18 years, categorized by chronological age and stage of maturation (pre, circa or post puberty) based on their years from peak height velocity (PHV).

Main outcome measures: Knee valgus was evaluated during the tuck jump assessment via two-dimensional analysis. Participants were subjectively classified as minor (<10°), moderate (10-20°), or severe (>20°) and using these classifications, scored as follows: 0 = no valgus; 1 = minor; 2 = moderate; 3 = severe.

Results: A trend of higher valgus scores were shown in the younger age groups and pre-PHV players. The lowest frequency of "no valgus" were in the U18s and post-PHV players. The highest percentage of "severe" scores were in the U13s. Knee valgus scores were significantly lower in the U18s on both legs than all other age groups ($p < 0.001$), except for the U16s. Post-PHV players' scores were significantly lower than pre-PHV youth on the right leg ($p < 0.001$), and both pre- and circa-PHV players on the left leg ($p < 0.001$). Noteworthy inter-limb asymmetries were evident in the U14s, U15s and circa-PHV players.

Conclusions: Reductions in knee valgus with incremental age and during the later stages of maturation indicate that this risk factor is more prevalent in younger players. Inter-limb asymmetry may also emerge around the time of the peak growth spurt and early adolescence, potentially increasing the risk of traumatic injury.

Key words: Valgus, injury risk, asymmetry

INTRODUCTION

Recent data show a trend of increased lower extremity injury with each sequential playing level in youth soccer players, indicating their relevance as a specific target group for injury risk reduction strategies (1, 2). Peak height velocity (PHV) has been defined as the age at which the maximum rate of growth occurs during the adolescent growth spurt (20). A period of heightened risk appears around this time (3), which in part may be due to rapid changes in stature and mass, but is also associated with altered movement and motor control strategies (3, 4, 5)

In male youth soccer, approximately 71-80% injuries occur mainly in the lower extremities, predominantly to the upper thigh, knee and ankle (1, 6). The highest proportion of injuries to the knee are ligamentous in nature, largely occurring in the medial collateral ligament (1, 6, 7). A rate of 0.71 knee injuries per player per year has been reported, equating to an absence of 17 training days and 2 matches per knee injury (7). Furthermore, the most frequent site of severe injury (> 28 days' time loss) is the anterior cruciate ligament (ACL) (8). Primary injury mechanisms for these structures have been identified, including a non-contact incident whereby the knee is positioned in valgus during landing and deceleration movements (9, 10). Prospective identification of players who demonstrate high-risk movement patterns using appropriate screening protocols may aid in the prevention of traumatic events via targeted neuromuscular training techniques (11).

Kinematic assessments are considered useful in the identification of non-contact knee injury risk (11, 12, 13, 14, 15, 16). A major focus has often been applied to female athletes (12, 13, 24); however, aberrant landing kinematics have also been reported in male youth soccer players who subsequently sustained an anterior cruciate ligament (ACL) injury versus non-injured controls (15). However, there is a paucity of research to analyze the effects of age and maturation on knee joint kinematics in this cohort. Boys appear to demonstrate kinematic changes at the knee, with reductions in valgus alignment as they progress through maturation (17, 18, 19). Male youth soccer players who participate in the U14 to U16 chronological age groups also appear to be at a greater risk of knee injury (7) which may be due to periods of rapid growth. In the context of a soccer academy, players compete and are typically screened in their respective chronological age groups; however previous data indicate that knee valgus may be influenced by the stage of maturity (18). Thus, quantifying the effects of age and maturation on knee valgus motion during repeated jumping tasks may assist coaches in identifying players who demonstrate high risk kinematics and developmental trends associated with age and different stages of maturity.

Cumulatively, despite the high frequency of knee injuries there is limited evidence available to determine the influence of age and maturation on knee joint kinematics using coach-friendly diagnostics in male youth soccer players. The aim of this study was to examine possible age- and maturity-related differences in dynamic knee valgus using the tuck jump assessment in elite male youth soccer players.

METHODS

Experimental Design

This study employed a cross-sectional design to assess the effects of chronological age and stage of maturation on dynamic knee valgus during the tuck jump assessment (TJA). Participants were required to attend their respective clubs' training grounds on two occasions separated by a period of seven days. The first session was used for familiarization and data were collected in the second session. Standardization procedures were replicated at each test session including the warm up, test set up and participant instructions. This included eating according to their normal diet, not drinking substances other than water one hour before, and refraining from strenuous exercise at least 48 hours prior to testing.

Participants

Four hundred elite male youth soccer players from the academies of six professional English soccer clubs volunteered to take part in the study. Descriptive statistics are provided for each chronological age and maturation group in tables 1 and 2 respectively. Maturation was calculated using a previously suggested regression analysis (20). All players undertake regular neuromuscular training (inclusive of skill, balance, plyometrics and resistance training) as provision of these modes is a requirement of the clubs to maintain their academy status. None of the players reported injuries at the time of testing and were participating regularly in football training and competitions. Parental consent, participant assent and physical activity readiness questionnaires were collected prior to the commencement of testing. Ethical approval was granted by the institutional ethics committee.

Table 1 Mean (s) values for participant details per chronological age group

Age Group	N	Age (yrs.)	Body Mass (kg)	Stature (cm)	Sitting Height (cm)	Maturity Offset
U11	58	11.2 ± 0.6	37.8 ± 5.8	144.0 ± 6.7	75.9 ± 4.8	-2.6 ± 0.5
U12	45	12.1 ± 0.6	40.3 ± 5.7	149.2 ± 5.9	79.3 ± 4.7	-2.0 ± 0.6
U13	56	12.8 ± 0.6	44.7 ± 8.8	155.8 ± 9.1	83.8 ± 6.8	-1.2 ± 0.7
U14	74	14.0 ± 0.5	50.2 ± 9.2	162.8 ± 9.4	84.2 ± 13.0	-0.1 ± 0.9
U15	64	15.3 ± 0.6	60.9 ± 8.4	172.2 ± 7.6	91.6 ± 5.3	1.0 ± 0.6
U16	60	16.1 ± 0.6	65.3 ± 8.1	175.8 ± 7.0	92.1 ± 5.7	1.8 ± 0.6
U18	43	17.5 ± 0.8	72.0 ± 6.5	178.9 ± 5.9	93.2 ± 4.2	2.9 ± 0.7

Table 2 Mean (s) values for participant details for each maturation group

Maturation group	N	Age (years)	Body mass (kg)	Stature (cm)	Leg length (cm)	Maturity offset
Pre PHV	135	11.9 ± 1.1	39.7 ± 6.4	148.2 ± 7.5	74.6 ± 3.5	-2.2 ± 0.6
Circa PHV	83	14.4 ± 0.9	51.8 ± 6.7	164.8 ± 7.6	82.3 ± 3.6	0.0 ± 0.3
Post PHV	129	16.1± 1.1	66.8 ± 8.0	176.6 ± 6.7	88.6 ± 4.7	2.0 ± 0.8

PHV = peak height velocity

Procedures

Anthropometry: Body mass (kg) was measured on a calibrated physician scale (Seca 786 Culta, Milan, Italy). Standing and sitting height (cm) were recorded on a measurement platform (Seca 274, Milan, Italy).

Biological Maturity: Stage of maturation was calculated in a non-invasive manner utilizing a regression equation comprising measures taken during the data collection period of age, body mass, standing height and sitting height (Mirwald, 2002). Using this method, maturity offset (calculation of years from PHV) was completed (equation 1). The equation has been used previously to predict maturational status in paediatric research with a standard error of approximately 6 months (Mirwald et al., 2002).

Maturity offset =

$$-9.236 + [0.0002708 \times \text{leg length and sitting height interaction}]$$

$$- [0.001663 \times \text{age and leg length interaction}]$$

$$+ [0.007216 \times \text{age and sitting height interaction}]$$

$$+ [0.02292 \times \text{weight by height ratio}]$$

[equation 1]

Tuck Jump Assessment. Tuck jumps were performed in place for 10 consecutive repetitions and the technique of each participant was visually graded for the presence of knee valgus based on previous recommendations (16). A two-dimensional video camera (Samsung, New Jersey, USA) was positioned in the frontal plane at a height 0.70m, and a distance of five meters from the landing area to capture the test. Knee valgus was estimated by measuring the angle created by lines drawn between the hip, knee and ankle joint centres (Noyes, Barber-Westin, Fleckenstein, Walsh & West, 2005). Frontal plane projection angles were then subjectively classified at the point of maximum knee flexion as minor (<10°), moderate (10-20°), or severe (>20°). The classifications were determined using pilot data and agreement between expert raters (n = 5) including experienced strength and conditioning coaches and rehabilitation specialists. Also, previous literature has shown that frontal plane projection valgus angles ranging from 1-9° are to be expected for physically active individuals, albeit in adult populations, during drop jumping tasks in non-injured participants (21). Using these classifications knee valgus in the tuck jump was scored as follows: 0 = no valgus; 1 = minor; 2 = moderate; 3 = severe (figure 1). Recorded deficits were marked if the respective knee valgus score was present on two or more repetitions (22) and the maximum score was used for the analysis. Scores were marked retrospectively by the same rater who was part of the research team and is a certified strength and conditioning specialist.

0 **1** **2** **3**

Figure 1. Knee valgus scoring classifications

Statistical Analysis

Descriptive statistics were calculated for each sub-group. A Kruskal-Wallis test was performed to determine the existence of any between group differences in tuck jump knee valgus score with the level of significance set at alpha level $p \leq 0.05$. Separate analyses were performed to examine between group differences for a range of chronological age groups that are representative of those used in an elite soccer academy (U11-U18). A secondary analysis was also employed, grouping players by their stage of maturation (pre-, circa- or post-PHV). To account for the reported error (approx. 6 months) in the equation (20), players were grouped into discrete bands based on their maturational offset (pre -PHV = <-1, circa-PHV = -0.5 to 0.5, post-PHV = >1). Players who recorded a maturational offset between -1 to -0.5 and 0.5 to 1 were subsequently removed from the data set when players were analysed by stage of maturation. Post-hoc analyses was assessed using Mann-Whitney U Tests to determine significant between-group differences. Further analysis included a Wilcoxan Signed Rank test to assess differences in performance between limbs for the whole sample and for each sub-group. The frequency of knee valgus scores were also calculated on each leg for each chronological age and maturation group. All data were computed through Microsoft Excel® 2010. Kruskal-Wallis and Wilcoxan Signed Rank tests were processed using SPSS® (V.21. Chicago Illinois). Intra-rater reliability for knee valgus scores in the repeated tuck jump assessment was assessed using kappa (*k*) coefficient. In order to do this, a sample including the videos of 50 participants were assessed on two occasions separated by a period of one week to determine the accuracy and repeatability of subjectively classified scores.

RESULTS

Intra-rater reliability for knee valgus score was deemed strong ($k = 0.89$). Median and mode knee valgus scores on the right and left legs are displayed in table 3 for all chronological age and maturation groups. The U18s reported significantly lower knee valgus scores on the right leg compared to all other age groups ($p < 0.001$), except for the U16s. On the left leg, knee valgus scores were significantly higher in the U11s and U12s than all age groups apart from the U13s, and significantly lower scores were recorded in the U18s ($p < 0.001$). A trend towards significance was shown with lower right leg knee valgus scores for the U16s versus the U13s ($p = 0.058$) and U12s ($p = 0.083$). When analyzed by maturation, right leg scores were highest in the pre-PHV group; however, these differences were only significant when comparing the pre- and post-PHV groups ($p < 0.001$). On the left leg, players in the post-PHV group recorded significantly lower scores than both the circa- and pre -PHV players ($p < 0.001$).

With all the players combined, between-limb comparisons revealed that knee valgus scores were significantly higher on the right leg ($p < 0.001$). The same pattern was observed in the U14-U18 chronological ages and for the circa and post-PHV maturation groups with

no significant between-limb differences in the U11-U13s and for the pre-PHV players. Data in table 3 shows that inter-limb asymmetry median and mode scores were evident in the U14s, U15s (2:1 right vs. left), and the U18s (1:0 right vs. left). The same pattern of inter-limb differences was observed when analyzed by maturation (table 3).

Table 3 Knee valgus median, interquartile range and mode scores for each group

	Valgus right leg		Valgus left leg	
Group	**Median**	**Mode**	**Median**	**Mode**
U11	2 (1-2)	2	2 (1-2)	2
U12	2 (1-2)	2	2 (1-2)	2
U13	2 (1-2)	2	2 (1-2)	2
U14	2 (1-2)	2	1 (1-2)	1
U15	2 (1-2)_	2	1 (0-1)	1
U16	1 (1-2)	1	1 (1-2)	1
U18	1 (0-1)	1	0 (0-1)	0
Pre PHV	2 (1-2)	2	2 (1-2)	2
Circa PHV	2 (1-2)	2	1 (1-2)	1
Post PHV	1 (1-2)	1	1 (0-1)	0

PHV = peak height velocity

The distribution of knee valgus scores for each chronological age and maturation group are displayed in figure 2. The greatest frequency of no valgus scores were recorded in the U18s and the post pubertal group. A greater frequency of moderate and severe scores were present in the younger chronological age groups and the players who were pre- and circa-PHV. A reduction in the combined percentage of moderate and severe scores was also shown in the older chronological age groups on both legs. This pattern was consistent when the data were analyzed by maturation, with circa- and post-PHV players displaying reductions in combined moderate and severe knee valgus scores than those who were pre-PHV. The highest percentage of severe scores was shown in the U13s and pre-PHV group on the right leg.

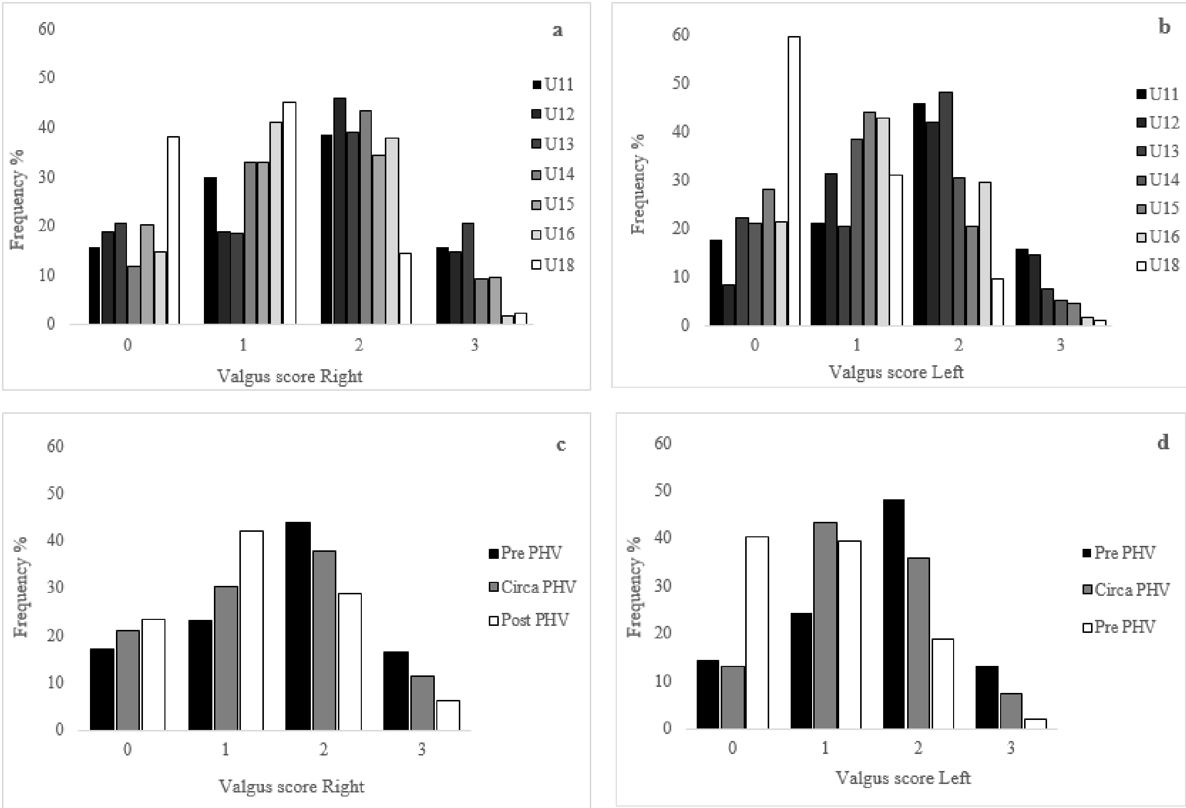

Figure 2a-d Frequency (%) of knee valgus scores for each group

DISCUSSION

The current study assessed the effects of chronological age and stage of maturation on the presence of knee valgus during the tuck jump assessment in elite male youth soccer players. Results showed reductions in knee valgus mode scores and a lower frequency of "moderate" and "severe" valgus scores with advancing age and stage of maturation. The highest percentage of severe scores were in the U13s and pre-PHV players on the right leg. Knee valgus scores were also significantly greater on the right leg when all the players were combined, with sub-group analysis showing noteworthy inter-limb asymmetry in the U14-U15 chronological age groups and players who were circa-PHV.

In the current study, all chronological age groups apart from the U18s recorded knee valgus mode scores >1 during the tuck jump assessment as measured via frontal plane projection angles, indicating that this risk factor was present to some degree in the majority of elite male youth soccer players who participated. Greater valgus motion on landing is a high risk mechanism for incidence of ACL and MCL injury (23, 24, 25), and the latter has been reported as the most frequently occurring knee injury in this cohort (1, 7). Untrained youths who do not regularly undertake strength and plyometric training activities are more likely to demonstrate knee valgus malalignment (17). The results of the present study reinforce the need for age appropriate neuromuscular training to target strength and motor control deficits in order to reduce their relative risk of injury (22, 26).

The results from this study show a trend of reduced knee valgus scores with advancing age and stage of maturation. These findings are consistent with those of previous literature examining recreational male youth soccer players (19). Previous literature has observed reductions in ground reaction forces relative to bodyweight with maturation during a drop jump manoeuvre (27). These data indicate that with advanced age and maturation, athletes are better able to attenuate landing forces due to utilisation of more effective movement strategies to dissipate force (28). Reductions in valgus could be due to the benefits of maturation providing increased strength and motor control (29), and/or chronological age may represent a surrogate of training age, whereby older players have adapted positively from a greater training history.

When the data from all players was pooled, knee valgus scores were significantly greater on the right leg. The same pattern was observed for all chronological age and maturation groups, notwithstanding the U11-U13s and players who were pre pubertal players. Movement variability during jumping tasks is more evident in younger athletes (30), which may explain the discrepancy between players who were pre pubertal in comparison to those who were older and at a later stage of maturation in the present study. Greater knee valgus scores on the right leg may indicate that limb dominance is evident in elite male youth soccer players and this appears to emerge from the onset of the U14 chronological age group (as indicated by asymmetrical median and mode scores), continuing through PHV and into early adolescence. Inter-limb asymmetry in foundational movement tasks has been reported to increase during this period (4) due to physiological adaptations on the dominant leg in youth soccer players (31). Thus, increases in leg dominance may be an age- and maturity-related injury risk factor. A plausible explanation could be that the majority of participants in this study were right footed, and with greater exposure to soccer specific practice and competitions, players may become more accustomed and competent at landing and stabilizing on their left leg. While no data are available to confirm this in youth athletes, in elite adult soccer players, the distribution of non-contact ACL injuries showed that 74.1% of males injured their dominant (kicking) leg (32). Further research is required to analyze prospective relationships between leg dominance and injury risk in elite male youth players.

Inter-limb asymmetrical median and mode scores were evident in the U14s, U15s and U18 and players who were circa- and post-PHV. Of particular note, the asymmetry scores for the U14s and U15 groups and for the circa-PHV group may reflect an increased injury risk (2:1 right vs. left comparison). Also, the highest frequency of severe knee valgus scores were recorded in the U13s. Recent data have shown that elite male youth soccer players are particularly susceptible to injury between the ages of 13.5 to 14.5 years (3, 33). This could be attributed to potential alterations in motor control that may emerge during periods of rapid growth (5). Subsequently, heightened risk and the potential for a greater incidence of overuse and/or traumatic knee injury may also be present for players in these groups (3, 33). However, this requires further investigation to examine if greater valgus scores and asymmetry between limbs increases the risk of injury in this cohort.

SUMMARY AND PRACTICAL APPLICATIONS

To the author's knowledge this is the first study to provide cross-sectional data in elite male youth soccer players using the tuck jump assessment to examine the effects of chronological age and stage of maturation on knee joint kinematics during a dynamic jump-landing task. Reductions in knee valgus mode score were shown with advancing chronological age and during later stages of maturation, which could be linked to enhanced relative strength and improved motor control. Greater knee valgus scores on the right leg for the whole sample and certain age and maturation groups indicates the potential emergence of limb dominance in elite male youth soccer players. Furthermore, noteworthy inter-limb knee valgus asymmetries were present in the U14-U15 chronological age groups and for players who were circa-PHV indicating that these groups should be a target for injury risk reduction strategies. This aberrant movement pattern which appears to emerge during periods associated with rapid growth in stature may increase the risk of traumatic injury due to asymmetrical loading of passive knee structures.

Quantifying the effects of chronological age and stage of maturation on knee valgus motion during the TJA will assist coaches in identifying players who demonstrate high risk kinematics in an affordable and easy to administer way. Aberrant landing mechanics appear to be more pronounced during periods of rapid growth and subsequent gains in body mass, specifically in the U13s-U15s and circa-PHV groups. These groups should be considered an important focus group for injury prevention strategies, with practitioners targeting any neuromuscular deficits through the use of developmentally-appropriate and technique-driven exercise prescription. Specifically, practitioners are advised to adopt an integrative neuromuscular training (INT) approach to program design (14, 34, 35), which seeks to develop fundamental movement skills and muscular strength through the use of resistance training, balance activities and plyometrics. Research shows that this form of training should be initiated during pre-adolescence and maintained through adolescence to enhance skill related fitness and reduce the risk of sports related injury (35, 36).

REFERENCES

1. Price RJ, Hawkins RD, Hulse MA, Hodson A. The football association and medical research programmeme: an audit of injuries in academy youth football. *Br J Sports Med. 2004;* 38: 466-471.
2. Schmikli SL, de Vries WR, Inklaar H, Backx FJ. Injury prevention target groups in soccer: injury characteristics and incidence rates in male junior and senior soccer players. *J Sci Med Sport.* 2011; 14: 199-203.
3. van der Sluis A, Elferink-Gemser MT, Coelho-e-Sliva MJ, Nijboer JA, Brink MS and Visscher C. Sports injuries aligned to peak height velocity in talented pubertal soccer players. *Int J Sports Med*. 2014; 35: 351–355.
4. Atkins, SJ, Hesketh, C, Sinclair, JK. The presence of bilateral imbalance of the lower limbs in elite youth soccer players of different ages. *Journal Strength & Cond Res*. In press.
5. Philippaerts RM, Vaeyens R, Janssens M, Van Renterghem B, Matthys D, Craen R, Bourgois J, Vrijens J, Beunen GP, and Malina RM. The relationship between peak height velocity and physical performance in youth soccer players. *J Sports Sci*. 2006; 24: 221–230.
6. Le Gall, F, Carling C, Reilly T, Vandewalle H, Chruch, J, Rochcongar P. Incidence of injuries in elite French youth soccer players; a 10-season study. *AM J Sports Med*. 2006; 34: 928-938.
7. Moore O, Cloke D, Avery P, Beasley I, and, Deehan D. English premiership academy knee injuries: lessons from a 5 year study. *J Sports Sci*. 2011; 29: 1535–1544.
8. Volpi P, Pozzoni R, Galli M. The major traumas in youth football. *Knee Surg Sports Traumatol Arthrosc*. 2003; 11: 399-402.
9. Walden M, krosshaug T, Bjornboe J, Andersetn TE, Faul O, Hagguland M. Three distinct mechanisms predominante in non-contact anterior cruciate ligament injuries in male professional football players: a systematic video analysis of 39 cases. *Br J Sports Med*. doi:10.1136/bjsports-2014-094573.

10. Wijdicks, CA, Griffith, CJ, LaPrade, R, Spiridonov, SI, Johansen, S, Armitage, BM and Engebretsen, L. Medial Knee Injury: Part 2, Load Sharing Between the Posterior Oblique Ligament and Superficial Medial Collateral Ligament. *AM J Sports Med. 2009;* 37: 1771-1776.
11. Read, PJ, Oliver, JL, De Ste Croix, MBA, Myer, GD and Lloyd, RS. Neuromuscular Risk Factors for Knee and Ankle Ligament Injuries in Male Youth Soccer Players. *Sports Med*. 2016b; 46; 1059-1066.
12. Myer GD, Paterno MV, Ford KR, Quatmen CE, Hewett TE. Rehabilitation after anterior cruciate ligament reconstruction: criteria-based progression through the return-to-sport phase. *JOSPT*. 2006; 36: 385-402.
13. Myer GD, Ford KR, Khoury J, Succop P, Hewett TE. Development and validation of a clinic based prediction tool to identify female athletes at high risk of ACL injury. *AM J Sports* Med. 2010; 38: 2025-2033.
14. Myer GD, Brent JL, Ford KR, et al. Real-time assessment and neuromuscular training feedback techniques to prevent ACL injury in female athletes. *Strength Cond J*. 2011a; 33: 21-35.
15. Padua, DA, DiStefano, LJ, Beutler, AI, de La Motte, SJ, DiStefano, MJ, Marshall, SW. The landing errors scoring system as a screening tool for an anterior cruciate ligament injury-prevention programme in elite-youth soccer athletes. *J Athl Train. 2015;* 50: 589-595.
16. Read PJ, Oliver JL, De Ste Croix MBA, Myer GD, Lloyd RS. Reliability of the tuck jump screening assessment in elite male youth soccer players. *J Strength Cond Res*. In press. 2016a
17. Noyes FR, Barber-Westin SD, Fleckenstein C, Walsh C, West J. The drop jump screening test: difference in lower limb control by gender and effect on neuromuscular training in female athletes. *AM J Sports Med*. 2005; 33: 197-207.
18. Schmitz RJ, Schultz SJ, Nguyen AD. Dynamic valgus alignment and functional strength in males and females during maturation. *J Athl Train*. 2009; 44: 26-32.
19. Yu B, McClure SB, Onat, JA, Guskiewicz KM, Kirkendall DT, Garrett WE. Age and gender effects on lower extremity kinematics of youth soccer players in a stop-jump task. *AM J Sports Med*. 2005; 33: 1356-1364.
20. Mirwald RL, Baxter-Jones ADG, Bailey DA, Beunen GP. An assessment of maturity from anthropometric measurements. *Med Sci Sports Exerc;* 2002. 34: 689–694.
21. Herrington l, Munro A. Drop jump landing knee valgus angle; normative data in a physically active population. *Phys Ther Sport*. 2010; 11: 56-59.
22. Myer GD, Stroube BW, DiCesare, Brent JL Ford KR, Heidt RS, Hewett, TE. Augmented feedback supports skill transfer and reduces high-risk injury landing mechanics: a double-blind, randomized controlled laboratory study. *Am J Sports Med*. 2013; 41: 669-677.
23. Ford KR, Myer GD and Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med. Sci Sports Exerc*. 2003; 35: 1745–1750.
24. Hewett TE, Myer GD, Ford KR et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *AM J Sports Med*. 2005; 33: 492-501.
25. Indelicato, PA. Isolated Medial Collateral Ligament Injuries in the Knee. *J AM Acad Orthop Surg*. 1995; 3:9-14.
26. Stroube BW, Myer GD, Brent JL, Ford KR, Heidt RS, Jr., Hewett TE. Effects of task-specific augmented feedback on deficit modification during performance of the tuck-jump exercise. *J Sport Rehabil*. 2013; 22:7-18.

27. Quatman CE, Ford KR, Myer GD, Hewett TE. Maturation leads to gender differences in landing force and vertical jump performance: a longitudinal study. *AM J Sports Med*. 2006; 34: 806–813.
28. Swartz EE, Decoster LC, Russell PJ, Croce RV. Effects of developmental stage and sex on lower extremity kinematics and vertical ground reaction forces during landing. *J Athl Train*. 2005; 40: 9-14.
29. Jones MA, Hitchen PJ, Stratton G. The importance of considering biological maturity when assessing physical fitness measures in girls and boys aged 10 to 16 years. *Annals Hum Biol*. 2000; 27: 57-65.
30. Gerodimos V, Zafeiridis A, Perkos S, Dipla K, Manou V, Kellis S. The contribution of stretch-shortening cycle and arm-swing to vertical jumping performance in children, adolescents, and adult basketball players. *Ped Ex Sci.* 2008; 20: 379-389.
31. Daneshjoo A, Rahnama N, Mokhtar A, Yusof A. Bilateral and unilateral asymmetries of isokinetic strength and flexibility in male young professional soccer players. *J Human Kinetics.* 2013; 36: 45-53.
32. Brophy R, Silvers H, Gonzales T, Mandelbaum B. Gender influences: the role of leg dominance in ACL injury among soccer players. *BR J Sports Med*. 2010; 44: 694-697.
33. van der Sluis A, Elferink-Gemser MT, Brink MS, Visscher C. Importance of peak height velocity timing in terms of injuries in talented soccer players. *Int. J. Sports Med*. 2015; 36: 327-332.
34. Myer, GD, Ford, KR, Palumbo, JP, and Hewett, TE. Neuromuscular training improves performance and lower extremity biomechanics in female athletes. J Strength Cond Res. 2005; 19:51–60.
35. Myer, GD, Faigenbaum, AD, Ford, KR, Best, TM, Bergeron, F, Hewett, TE. When to initiate integrative neuromuscular training to reduce sports-related injuries in youth? *Curr Sports Med Rep*. 2011b; 10: 155–166.
36. Faigenbaum, AD, Farrell, A, Fabiano, M, Radler, T, Naclerio, F, Ratamess, NA, Kang, J, and Myer, GD. Effects of integrative neuromuscular training on fitness performance in children. *Ped Exerc Sci*. 2011; 23: 573–584.