DIFFERENCES IN LANDING STRATEGIES DURING A VERTICAL DROP JUMP TEST AS A FUNCTION OF GENDER AND AGE IN YOUTH ÉLITE SOCCER PLAYERS

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We analyzed the kinematics and kinetics of vertical drop jump landing in a group of 85 (20 females) elite youth soccer players (U10-U11 and U17). Peak knee flexion and knee varus increased in male players as a function of age; normalized peak vertical ground reaction forces decreased with age and in female players. Preliminary data can be used to build reference tables for this specific population and can help to correct dangerous landing strategies, and to keep each player's development monitored. We also suggest that education of safe landing technique would prevent dangerous knee postures.

KEYWORDS: ACL injury, prevention, knee varus, kinematics, kinetics.

INTRODUCTION: The vertical drop jump (VDJ) test is aimed to assess lower extremity neuromuscular control and dynamic and static balance abilities in a jump-landing condition. VDJ was proposed as a screening test in sports with a high risk of non-contact ACL injury, since a significant association was reported between frontal-plane knee motion during a VDJ and knee injury among post-menarchal female soccer players (O'Kane et al., 2016). In particular, the most dangerous behaviour for ACL rupture during a landing task is a medial collapse at the knee level (dynamic valgus), combined with external knee abduction moments (Nilstad et al., 2014). Reduced knee flexion and high vertical ground-reaction forces (vGRFs) are evidence of lower limb stiffness and are considered additional injury risk factors during landing tasks (Leppänen et al., 2017). Leg stiffness influences the mechanics and kinetics of the body's interaction with the ground (Peng, 2011).
However, no previous research extensively analysed the combined kinematics and kinetics of a bipodal VDJ test in a cohort of élite youth soccer players. Thus, this study intends to characterize and evaluate the VDJ landing strategies in youth elite soccer players. Information about the knee biomechanics and age/sex-related differences may provide guidelines in the delivery of the VDJ test for prevention and screening purposes in this specific population.

METHODS: Eighty-five youth football players were recruited among the Academy of an Italian "Serie A" professional team and split into three groups: (i) females U10-U11, (ii) males U10-U11, (iii) males U17, as reported in Table 1. Footedness was obtained based on the preferred foot in kicking a soccer ball. First and second landing kinetic data were measured with four force plates (BTS, Milano, Italy); the three-dimensional trajectory of 22 reflective markers was also recorded by means of a 6-infrared camera optoelectronic motion capture system (BTS, Milano, Italy). Landmark positions were C7, sacrum, right and left greater trochanters, anterior superior iliac spine, medial and lateral femoral epicondyles, fibula heads, medial and lateral malleoli, first and fifth metatarsal heads, calcanei. (Figure 1). Players wore trainers and minimal clothing; they completed three trials of a 30-cm high VDJ test while keeping their hands on their hips, under the supervision of an experienced operator.

Table 1: Participants' anthropometrics (mean and SD) and characterization (R: right, L: left).

Group	n	Sex	Age	Height (m)	Body mass (kg)	BMI (kgm^{-2})	Footedness
i	20	F	U10-11	1.38 (0.07)	33.8 (7.1)	17.5 (2.4)	13 R, 8 L
ii	37	M	U10-11	1.45 (0.06)	37.2 (5.5)	17.7 (2.5)	26 R, 11 L

iii	19	M	U17	1.83 (0.04)	70.5 (6.8)	21.3 (2.2)	16 R, 3 L

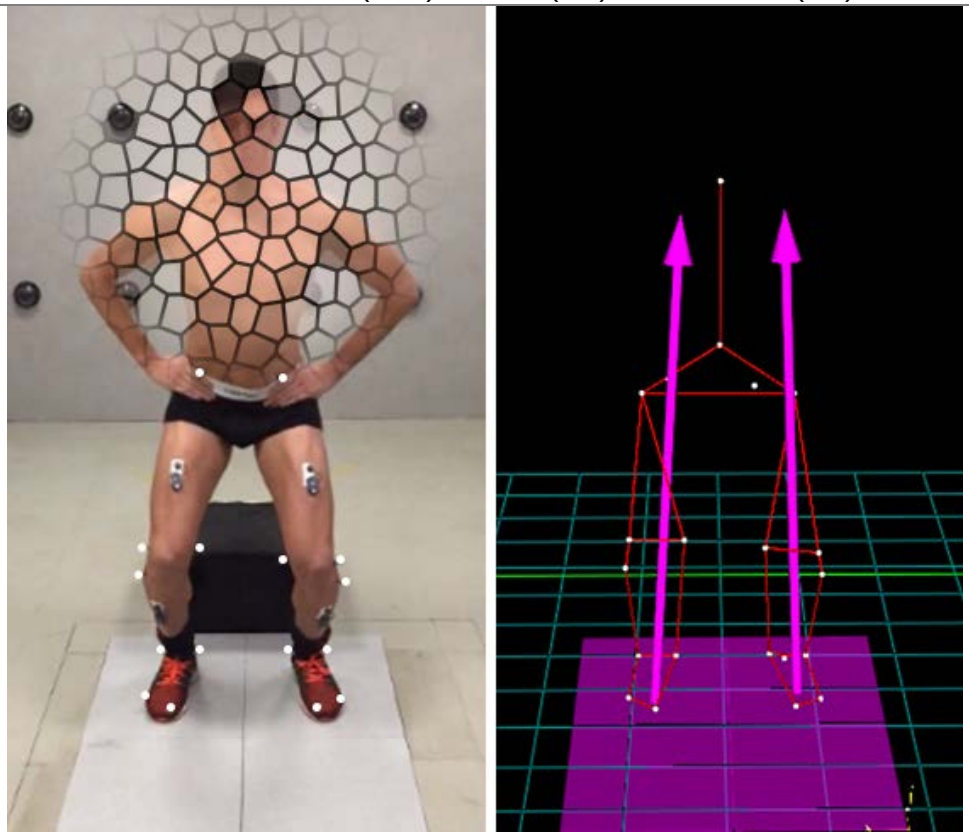

Figure 1: Landmark positions and corresponding three-dimensional reconstruction.

Participants were previously instructed to perform the VDJ with the bounce drop jump (BDJ) technique, i.e. with a downward movement during landing and a subsequent vertical jump (Bobbert et al., 1987). The first valid trial in terms of correct technique and performance was further analyzed for each subject. Custom software enabled extraction of the following variables: frontal-plane knee angle (KV; angles <180° correspond to knee varus, KV,), sagittal-plane knee angle (flexion/extension, KF, where 180° is full extension) computed at the maximum knee flexion instant; percentage load on the two limbs at landing; and peak vertical ground reaction force during push-off (pGRF), normalized by body weight. For each variable, symmetry indexes were computed as 100*(R-L)/R, where R and L were the right and left sides of the body, respectively.
In order to test any difference in KV, KF and pGRF in U10-U11 groups, a 2-way analysis of variance (ANOVA) with factors sex and side was performed. To test age-related differences in male players, U17 were compared to male U10-U11 with a 2-way ANOVA (factors: age and side). Independent samples Student's t-tests were used to check for differences in symmetry indexes. Significance was set at alpha<0.05 for all tests.

RESULTS: As shown in Figure 2, neither KV nor KF showed significant differences between U10-U11 males and females (sex factor, p>0.05). The behaviour of the dominant and non-dominant legs was also similar during landing (side factor, p>0.05). However, pGRF was significantly higher in the U10-U11 males (p=0.002). Symmetry indexes were comparable for males and females at the same age (p>0.05).
Both KV and KF was lower in older male players (age factor, p<0.001 and p=0.037); with no side-related differences (Figure 3). Normalized pGRF was reduced in U17 compared to U10-11 males (p<0.001). No symmetry index was significantly different between age groups.

DISCUSSION: The main result of this study is the preliminary characterization of male and female young elite soccer players performing VDJ.
The analyzed U10-U11 players were tested before their peak growth velocity and hormonal maturation (Bangsbo, 2007) and no clear differences emerged in the frontal and sagittal-

plane knee angle. Indeed, low frontal-plane knee distance during landing was previously associated with increased risk of lower extremity and knee injury only among post-menarchal female players (O'Kane et al., 2016).
The lower muscle mass in girls (Ali et al., 2013) was likely to be the reason of the reduced pGRF in U10-U11 females. Although we did not present data about adolescent female players based on males' data, future investigations could reveal age-related biomechanical differences. That is, males and females demonstrate substantial anatomical, hormonal, and neuromuscular differences after the onset of puberty that may influence the divergence between the sexes in ACL injury rates (Hewett et al., 2016). Consequently, greater knee valgus and lower knee flexion angles are more common in females compared to males during vertical drop-jump landing, especially during pubertal growth (Nilstad et al., 2014).

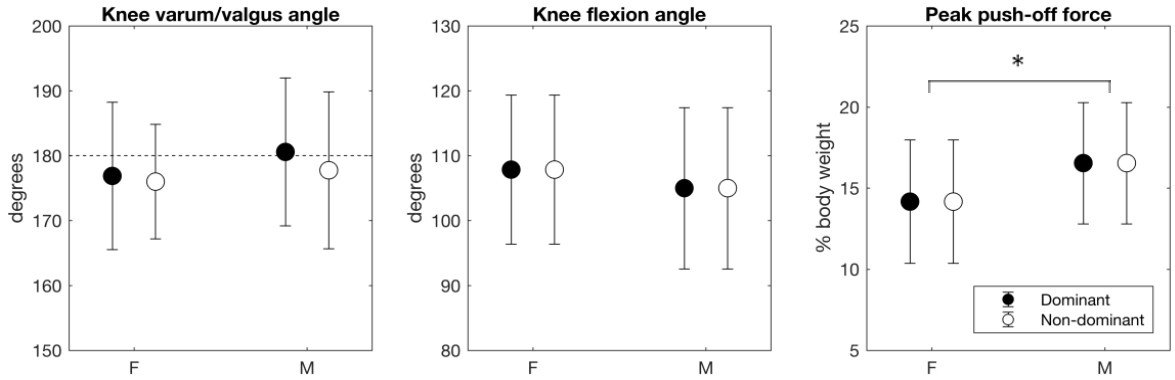

Figure 2: Mean (SD) frontal-plane knee angle (left), sagittal-plane knee angle (centre) and peak GRF during the VDJ, stratified for gender and side in U11-U10 players. *: significant difference between males and females (p<0.05).

In older players, we observed the development of a varus trend. Witvrouw et al. (2009) demonstrated that until the age of 12-13 years, soccer players generally show a genu valgus. From the age of 16, such trends probably change due to the high amount of practice-induced stress and strain imposed on the joints during growth (Witvrouw et al., 2009), and concurrent increases in hip abduction strength (Hewett et al., 2016). Such causes of genu varus should be systematically monitored during players' development in order to preserve knee ligaments and joint integrity.
U10-U11 male players showed a stiffer lower limb behaviour during landing, with a higher flexion angle and higher pGRF. This may place the ACL at an increased risk of injury (Leppänen et al. 2017) and may be dependent on (i) a not fully developed neuromuscular ability and consequent lack of coordination (Bangsbo, 2007) and/or potentially (ii) a different step height (30 cm) vs. body stature ratio, which was on average 1/6 and 1/5 for U17 and U10-11, respectively.

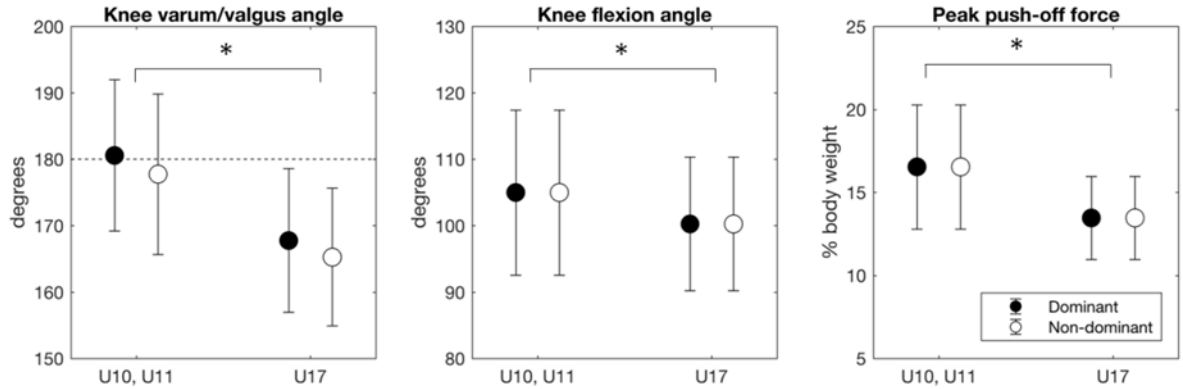

Figure 3: Mean (sd) of frontal-plane knee angle (left), sagittal-plane knee angle (centre) and peak GRF during the propulsive phase (right), stratified for age category and side in male players. *: significant difference between U11-U10 and U17 ($p<0.05$).

A word of caution regarding the jumping technique. Since the vertical drop jump can be performed with or without a downward movement upon landing, before push-off. These two styles are known as counter-movement drop-jump (CDJ) and bounce drop jump (BDJ). At push-off, the knee flexion angle is greater (lower flexion) in BDJ than in CDJ, and in BDJ larger muscles moments and larger power output are expected (Bobbert et al., 1987). In our investigation, even though the operator instructed all the players to perform the jump according to the BDJ technique consistently, it was difficult to guarantee exactly the same performance from all players. Different groups need to be assessed to understand how these variables may change over time. This would allow to clearly identify the most relevant variables that have to be analyzed in soccer players.

CONCLUSION: This study performed a quantitative knee biomechanics characterization of male and female young elite soccer players performing VDJ. Results showed no differences in landing knee kinematics among male and female players before their peak of growth and the development of a knee varus in older male players. VDJ data can help to create specific programs in order to correct dangerous landing strategies, if they are noted, and to keep each player's growth and development monitored. The education to a correct landing technique, preventing dangerous knee posture, may be an effective ACL prevention strategy (Hewett et al., 2016). The authors suggest that this process should be started at an early age, teaching young players the correct load acceptance maneuvers, coordination and proprioception. These preliminary considerations should be also noted when interpreting VDJ test results on youth players and may be used to build reference tables for this specific population.

REFERENCES

Ali, N., Rouhi, G., & Robertson, G. (2013). Gender, vertical height and horizontal distance effects on single-leg landing kinematics: implications for risk of non-contact acl injury. *Journal of Human Kinetics*, *37*, 27-38.

Bangsbo, J. (2007). *Aerobic and anaerobic training in soccer - with special emphasis on training youth players*. Copenhagen, Stormtryk ed.

Bobbert, M. F., Huijing, P. A., & Schenau, G. J. V. I. (1987). Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. *Medicine and Science in Sports and Exercise*, *19*(4), 332-38.

Hewett, T. E., Myer, G. D., Ford, K. R., Paterno, M. V., & Quatman, C. E. (2016). Mechanisms, prediction, and prevention of ACL injuries: cut risk with three sharpened and validated tools. *Journal of Orthopaedic Research*, *34*(11), 1843–1855.

Leppänen, M., Pasanen, K., Krosshaug, T., Kannus, P., Vasankari, T., Kujala, U. M.,.. Parkkari, J. (2017). Sagittal Plane Hip, Knee, and Ankle Biomechanics and the Risk of Anterior Cruciate Ligament Injury: A prospective study. *Orthopaedic Journal of Sports Medicine*, *5*(12).

Nilstad, A., Andersen, T. E., Kristianslund, E., Bahr, R., Myklebust, G., Steffen, K., & Krosshaug, T. (2014). Physiotherapists can identify female football players with high knee valgus angles during vertical drop jumps using real-time observational screening. *Journal of Orthopaedic & Sports Physical Therapy*, *44*(5), 358-365.

O'Kane, J. W., Tencer, A., Neradilek, M., Polissar, N., Sabado, L., Schiff, M. A. (2016). Is knee separation during a drop jump associated with lower extremity injury in adolescent female soccer players? *The American Journal of Sports Medicine*, *44*(2), 318-23.

Peng, H.-T. (2011). Changes in biomechanical properties during drop jumps of incremental height. *Journal of Strength and Conditioning Research*, *25*(9), 2510–2518.

Witvrouw, E., Danneels, L., Thijs, Y., Cambier, D., Bellemans, J. (2009). Does soccer participation lead to genu varum? *Knee Surgery Sports Traumatology Arthroscopy*, *17*, 422-27.