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Comparison of Drop Jump and Tuck Jump Knee Joint Kinematics in Elite Male Youth Soccer Players: Implications for Injury Risk Screening

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ABSTRACT

Context: Despite the popularity of jump-landing tasks being used to identify injury risk factors, minimal data currently exist examining differences in knee kinematics during commonly used bilateral jumping tasks. This is especially the case for rebounding-based protocols involving young athletes. ***Objective:*** The purpose of this study was to compare the frontal plane projection angle (FPPA) during the drop vertical jump (DVJ) and tuck jump assessment (TJA) in a cohort of elite male youth soccer players of varying maturity status. ***Methods:*** A total of 57 male youth soccer players from an English championship soccer club participated in the study. Participants performed three trials of the DVJ and TJA, during which movement was recorded with two-dimensional video cameras. FPPA for both right (FPPA-*r*) and left (FPPA-*l*) legs, with values <180º indicative of medial knee displacement. ***Results:*** On a whole-group level, FPPA-*r* (172.7 ± 7.4 º *versus* 177.2 ± 11.7 º; $p < 0.05$; *ES* = 0.46) and FPPA-*l* (173.4 ± 7.3 º *versus* 179.2 ± 11.0 º; $p < 0.05$; *ES* = 0.62) was significantly greater for both limbs in the TJA compared to the DVJ; however, these differences were less consistent when grouped by maturity status. FPPA-*r* during the TJA was significantly and moderately greater in the circa-PHV group compared to the post-PHV cohorts (169.4 ± 6.4 º *versus* 175.3 ± 7.8 º; $p < 0.05$; *ES* = 0.49). Whole group data showed moderate relationships for FPPA-*r* and FPPA-*l* between the TJA and DVJ; however, stronger relationships were shown in circa and post-PHV players compared to the pre-PHV cohort. ***Conclusions:*** Considering that the TJA exposed players to a larger FPPA and was sensitive to between-group differences in FPPA-*r*, the TJA could be viewed as a more suitable screen for identifying FPPA in young male soccer players.

KEY WORDS: tuck jump assessment, maturation, frontal plane projection angle, knee valgus

INTRODUCTION

The demands of soccer predispose male youth athletes to a heightened risk of injury; thus, these players should be considered a target group for the implementation of screening protocols to identify 'at risk' individuals [1]. Epidemiological data indicate that rapid decelerations are a frequent mechanism of injury, with the knee being the anatomical location at the greatest risk of severe injury [2]. Aberrant motor control strategies characterized by reduced abilities to effectively control limb motion during athletic movements are a proposed risk factor [3]. Quantifying movement competency in sport-relevant tasks should be considered an important component for injury risk reduction. Jump-landing assessments are frequently used within pre-participation screens to aid in the identification of injury risk [4-6]; however, research has indicated that there is a diverse range of assessment tools used within sports such as soccer, with a lack of consistency amongst practitioners [7]. The drop vertical jump (DVJ) is one of the most commonly used screening tools within the literature [4,8,9], and dynamic knee valgus measured during this test has previously been associated with a greater risk of anterior cruciate ligament (ACL) [8] and patellofemoral joint [10] injury. Abnormal landing kinematics during the DVJ have also been reported by elite male youth soccer players who subsequently sustained an ACL injury [5].

The validity of the DVJ as a screening tool for predicting ACL injury risk has recently been examined in elite female soccer players [11]. Medial knee displacement was associated with an increased risk of ACL injury; however, poor sensitivity and specificity of this measure was reported with the authors indicating that this test cannot predict ACL injuries [11]. It is plausible that constraining the task, whereby all participants drop from the same height, reduces the sensitivity when identifying individuals who display aberrant kinematics that are indicative of a greater injury risk. Jump heights exceeding 30 cm are likely to be achieved during competitive soccer practice and match play where the mechanism of injury occurs. Thus, protocols that quantify landing kinematics during movements that are representative of those performed relative to the individual (i.e. matched to their jump height) may be more sensitive in establishing the movement deficits such as reduced frontal plane knee control that may be associated with injury risk.

Screening assessments that involve repeated jumping tasks also require athletes to respond to movement perturbations and forces [12]. The tuck jump assessment (TJA) is a practical field-based test that utilizes this approach and has been developed to identify errors in plyometric technique that are associated with ACL injury risk factors [13,14]. More recently, it was shown in a sample of elite male youth soccer players that of the 10-criteria included in the original TJA [13], knee valgus was the only measure to display acceptable test re-test reliability [12]. The presence of knee valgus within the TJA is currently subjectively scored using either a dichotomous approach, "yes/no" [13] or an ordinal scale to more objectively rate the quality of the movement [12]. Limited data are currently available on frontal plane projection angles (FPPA) during the TJA in youth populations, measured quantitatively with practically viable methods.

While research has examined biomechanical differences in a range of jump-landing screening tests, invariably these have involved bilateral versus unilateral comparisons and primarily included adults [15,16]. Minimal data currently exist examining differences in knee kinematics during commonly used bilateral jumping tasks, especially rebounding-based protocols, and in particular involving young athletes. The DVJ and TJA challenge movement capabilities of individuals in contrasting jump-landing conditions; while the DVJ regulates drop height (e.g. 30 cm) and likely offers greater consistency across repeated measurements, the TJA reflects a more dynamic, reactive protocol that arguably possesses greater external validity but also heightened movement variability. Therefore, the purpose of this study was to examine knee valgus kinematics during the DVJ from a 30 cm box height and a repeated TJA in a cohort of elite male youth soccer players of varying maturity status.

METHODS

Design

This cross-sectional, observational study was designed to compare the peak FPPA obtained in both right and left legs during a DVJ and TJA among young male soccer players.

Participants

Fifty-seven elite male youth soccer players, aged 10-18 years, from the academy of an English championship professional soccer club volunteered to take part in this study. Body mass (kg) was measured on a calibrated physician scale (Seca 786 Culta, Milan, Italy). Standing and seated height (cm) were both recorded on a measurement platform (Seca 274, Milan, Italy) to the nearest 0.1 cm. Seated height was measured with participants sat on top of a standardized 1 m box, with height measured as the distance from the sitting surface to the top of the head [17]. Descriptive statistics for anthropometric variables are displayed in *table 1*. Biological maturation was estimated as years from peak height velocity (PHV) using a validated and non-invasive regression equation, which has a reported error of approximately six months [18]. Participants were allocated to one of three maturity groups: pre-PHV (n = 17), circa-PHV (n = 15), or post-PHV (n = 25). None of the players reported injuries at the time of testing and all were participating regularly in football training and competitions in accordance with the regulations set out by the Premier League Elite Player Performance Plan. 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 in accordance with the declaration of Helsinki.

Table 1 near here

Procedures

Participants were required to attend their respective club training grounds on two occasions separated by a period of seven days, during the preseason. The first session was used to familiarize participants with the test equipment and assessment protocols. During this session, participants were questioned to identify their preferred kicking leg (i.e. were they either "right-footed" or "left-footed"). In the second session, data were collected for the DVJ and TJA in a randomized, counterbalanced order. A 10-minute standardized dynamic warm up was completed prior to each test session, which included approximately 3-minutes of sub-maximal multidirectional running and roughly 7-minutes of dynamic mobilisation and activation exercises, which targeted the main muscle groups of the lower and upper extremities and gradually increased in terms of their speed of movement. Participants were asked to refrain from strenuous exercise at least 48 hours prior to testing and eat according to their normal diet, avoiding eating and drinking substances other than water one hour prior to each test session. To allow visible tracking of the knees, participants were instructed to wear shorts that covered down to approximately mid-thigh.

Drop vertical jump (DVJ)

Participants stood on top of a box at a height of 30 cm with their feet 35 cm apart. Instructions were to drop directly down and contact the floor ensuring no vertical elevation or sinking as they stepped from the box. Upon ground contact, players were instructed to minimize ground contact time and immediately perform a maximum vertical jump and then land on the floor and stick the landing in line with previous recommendations [19]. Participant's hands were freely available during the test in order to replicate a natural jump-landing position [20]. Three trials were performed, separated by one-minute recovery intervals.

Tuck jump assessment (TJA)

Participants stood on two vertical strips of tape which were 35 cm apart and connected by a horizontal line forming a H-Shape [13]. The test began by performing a countermovement followed by a jump in a vertical direction as high as possible while simultaneously pulling their knees up towards their chest. Tuck jumps were then repeatedly performed in place for a period of 10 seconds. Three trials of the TJA protocol were performed, separated by one-minute recovery intervals. Instructions were to jump as high as possible, land in the same footprint with each jump and to minimize ground contact time, utilizing a toe to mid-foot rocking landing strategy [13]. The H-Shape taped lines served as a visual guide to help the rater determine foot positioning faults during landing (e.g. feet not shoulder width apart, or not parallel).

Kinematic analysis

Two-dimensional (2D) video cameras were used to capture the test and the data were analyzed retrospectively using freely available software (Kinovea 0.8.23; Free Software Foundation, Boston, USA). Peak frontal plane projection angle (FPPA) was calculated by measuring the angle created by lines drawn between the hip, knee and ankle joint centres at the point of maximum knee flexion [19] and calculated for both the right (FPPA-*r*) and left (FPPA-*l*) legs. Maximum knee flexion angle was determined from the frame which indicated the lowest point of the landing task as observed on the video using the analysis software; an approach that is in accordance with previous research [16,27]. The FPPA was measured once for each DVJ trial. For the TJA, peak FPPA was calculated for each ground contact experienced during the protocol, with an average peak FPPA compiled across all ground contacts of each trial. The mean peak FPPA was then averaged across the three trials of the TJA and used for analysis. This approach has been shown to be valid and reliable for the quantification of knee valgus motion during a range of jump-landing tasks [21,22]. Values <180º were indicative of medial knee displacement. Kinematic data were collected at 50 Hz using a high-definition video camera (Samsung, New Jersey, USA) positioned in the frontal plane at a height 0.70 m, and a triangulated distance of five meters from the center of the capture area. To allow visible tracking of the knees, subjects were required to wear shorts with a line at approximately mid-thigh. The same rater marked and recorded each trial to maximize inter-rater consistency.

Statistical analyses

Descriptive statistics (mean ± sd) were calculated for all variables. A 3 (group) x 2 (test) x 2 (leg) mixed analysis of variance (ANOVA) test was used to determine any between-group differences for FPPA between each maturity group for both TJA and DVJ tests. Homogeneity of variance was tested using Levene's statistic, and where violated Welch's adjustment was used to calculate the F-ratio. When equal variance was or was not assumed, Tukey's HSD and Games-Howell post hoc tests were used respectively, to establish the origin of any between-group differences. Cohen's *d* effect sizes (ES) were calculated to interpret the magnitude of between group differences using the following classifications: standardized mean differences of 0.2, 0.5 and 0.8 for small, moderate, and large effect sizes respectively [23]. Pearson's correlation coefficients were used to determine the strength of relationship between measures of FPPA in both the TJA and DVJ. The magnitude of relationships in correlation analyses were classified as either; almost perfect (r = >0.9), very large (r = 0.7–0.9), large (r = 0.5–0.7), moderate (r = 0.3–0.5), small (r = 0.1–0.3) or trivial (r = <0.1) [24]. The level of significance was set at alpha level $p < 0.05$. Intra-rater reliability for FPPA was assessed using a two-way random intra-class correlation coefficient (ICC) with absolute agreement on a sub-section of participants ($n = 20$). To conduct the analysis, the rater viewed the same videos in a randomized order on two separate occasions, separated by a period of 7 days. All statistical tests were computed using SPSS® v.23 for Mac.

RESULTS

Data showed that 78% of participants preferred kicking with their right leg. Very large ICC (0.90; 0.86 – 0.93 (95% CI)) indicated that intra-rater reliability was strong. Results from the mixed ANOVA showed no main effect for "group" but a main effect for "test", with FPPA significantly greater (indicating more medial displacement) in the TJA compared to the the DVJ in the right leg (172.7 ± 7.4º *versus* 177.2 ± 11.7º; $p < 0.05$; $ES = 0.46$) and left leg (173.4 ± 7.3º *versus* 179.2 ± 11.0º; $p < 0.05$; $ES = 0.62$) respectively. Table 2 shows that when grouped by maturity status, FPPA-*r* was significantly greater during the TJA in the circa-PHV compared to post-PHV participants (169.4 ± 6.4º *versus* 175.3 ± 7.8º; $p < 0.05$; $ES = 0.49$). Apart from a significant difference between FFPA-*r* in the TJA and the FPPA-*l* during the DVJ for the circa-PHV group ($p < 0.001$; $ES = 1.13$), there were no other meaningful significant interaction effects ($p > 0.05$).

Table 2 near here

Whole-group analysis revealed moderate, significant relationships between FPPA in the DVJ and TJA for both right and left legs. When grouped by maturity, the strength of relationships varied for FPPA-*r* and FPPA-*l* between both screening assessments. Specifically, there were nonsignificant weak correlations for both FPPA-*r* and FPPA-*l* in the pre-PHV group, a significant large correlation for the FPPA-*l* in the circa-PHV group, while in the post-PHV cohort there were significant large and moderate correlations for FPPA-*l* and FPPA-*r*, respectively.

Table 3 near here

DISCUSSION

The current study examined the differences in peak FPPA in both limbs during the TJA and DVJ screening protocols in male youth soccer players of different maturity status. The main findings were that on a whole-group level, FPPA was significantly greater for both limbs in the TJA when compared to the DVJ; however, when grouped by maturity status, these differences were eliminated. There was also a significant and moderate difference in FPPA-*r* during the TJA between the circa-PHV and post-PHV cohorts. Correlation analysis revealed only moderate relationships for FPPA-*r* and FPPA-*l* between the TJA and DVJ; however, when grouped by maturity status, the strength of correlations was more varied with stronger relationships shown in circa and post-PHV players.

Previous research has shown differences in frontal plane knee motion between different lower limb screening tests [25]. Similarly, the current study revealed FPPA was significantly and moderately greater in both limbs during the TJA in comparison to the DVJ protocol. Both the TJA [13,14] and DVJ protocol [9] have been proposed as screening tools to assess ACL injury risk factors, with the DVJ being used more extensively within the literature. The results of the current study suggest that the TJA may offer a screening protocol that is more likely to expose aberrant frontal plane knee control during ground contact. Intuitively, this is due to the more reactive and repeated nature of the test when compared to the DVJ protocol that utilizes a single repetition from a standardized drop height. The DVJ may artificially induce feed-forward stabilization mechanisms, which have been shown to develop as a result of advancing age and maturation [20]. Conversely, the TJA is likely to better represent the ability of the neuromuscular system to provide adequate stabilization and force attenuation in response to each individual's jumping capabilities.

When grouped by maturity status, FPPA-*r* and FPPA-*l* were greater in the TJA compared to the DVJ; however, these differences did not reach significance. This indicates that when testing more homogenous maturity groups, the ability to discriminate between frontal plane knee motion during both screening protocols is reduced, albeit by sub-dividing into smaller maturity groups, the ability to detect significant between-group differences becomes more challenging. While no significant within-group differences in FPPA were shown across both screening tools, between-group analysis did reveal that FPPA-*r* during the TJA was moderately significantly greater in the circa-PHV group compared to the post-PHV cohort. This could be explained by the rapid growth in limb length that adolescents experience during and immediately after peak height velocity, which can lead to temporary decrements in motor control and neuromuscular function. This finding is commensurate with previous research examining jumping and landing performance in junior male soccer players [26-28] and heightened injury incidence data associated with the growth spurt [29].

Research examining frontal plane knee motion in female athletes has revealed strong agreement ($r = 0.93$) in knee valgus during vertical jump and drop vertical jump tests [30]. Owing to this similarity, the authors proposed that the vertical jump could be utilized as a practice measure of ACL injury risk; however, knee kinematics were analyzed during the pre-flight phase of the vertical jump and not during landing, meaning the results should be interpreted with caution. Conversely in the current study, on a whole group level the strength of relationships in FPPA between limbs (i.e. FPPA-*l* versus FPPA-*r*) in the DVJ and also in the TJA protocol, while significant, were only moderate which indicates that the magnitude of FPPA is likely to differ depending on which screening protocol is used.

The strength of correlation in FPPA between limbs in both DVJ and TJA tests appeared to vary according to the stage of maturity. Notably, the pre-PHV group failed to show any meaningful relationships in FPPA in either leg between the two tests; the circa-PHV revealed a significant large correlation for the FPPA-*l*, while significant large and moderate correlations for FPPA-*l* and FPPA-*r* were reported in the post-PHV cohort. Cumulatively, this suggests that increases in maturity will result in young males displaying more consistent FPPA during rebound-type activities. The weaker correlations in FPPA across the two screening tests displayed in the less mature cohort may reflect the more variable movement typically displayed by this population [31], which has been attributed to immature pre-frontal motor cortex activation negatively affecting coordinative abilities of younger children. Conversely, older and more experienced individuals will likely have developed more consistent and robust motor control strategies, and thus utilize similar degrees of frontal plane knee motion across the different test protocols. Practically, this may result in more mature individuals displaying similar risk profiles across different screening tests.

A final point of consideration is the fact that significant between-group differences in FPPA were noted in the right leg only, which means that the FPPA in the left leg did not differ between groups. Due to the high proportion of right-footed kickers in the study, this would infer that any growth-related discrepancies in frontal plane knee motion were most likely present in the kicking leg, while the FPPA in the stance leg was more consistent across the groups. Notably, significant large correlations in FPPA-*l* across both testing protocols were shown in both the circa- and post-PHV cohorts, while FPPA-*r* was only moderately correlated in the post-PHV cohort. Tentatively, this would support the notion of greater stability and consistency of movement in the stance leg, in particular as players become more mature and experienced. Speculatively, this trend may be due to the development of asymmetries in functional properties (e.g. muscular strength), which have been identified previously in Australian Football League athletes [32].

Certain limitations should be noted in this study. *Firstly*, kinematic data were collected using 2D video footage, which in comparison to "gold standard" 3D motion capture, does not account for movement in all planes of motion and segmental and joint rotations. However, research has shown acceptable agreement between 2D and 3D analysis methods [33,34], and many of the injury risk factors associated with the knee occur in the sagittal and frontal planes. Additionally, due to financial costs and time-consuming nature of testing, many 3D motion capture systems are impractical for applied settings, especially when attempting to screen large groups of young players in the setting of a soccer academy. *Secondly*, the point of maximum knee flexion was not quantified using a sagittal plane camera; however, the chosen method of determining the lowest point of the landing task has been validated in previous research [16,27]. *Finally*, correlation does not imply causation, and further research is required to better understand the reason for the variability in strength of relationships across the different maturity groups. Despite these limitations, the current study makes an original and significant contribution to the literature, indicating that practitioners should consider the maturational stage of young players when selecting screening tools and also when interpreting the kinematic data.

CONCLUSIONS

Practitioners should consider the findings of the current study when using jump-landing tasks to screen young male soccer players for aberrant lower limb movement patterns. The data indicate that the TJA was more likely to expose individuals who demonstrate greater FPPA-*r* and FPPA-*l* than the DVJ when analyzed on a whole-group level, and was able to detect differences in FPPA-*r* between the circa-PHV and post-PHV groups. Thus, in instances where available testing time is limited, the TJA may be viewed as a preferred screening tool. However, while the TJA may better reflect the dynamic nature of competitive soccer, thereby possessing greater external validity, the DVJ more stringently regulates drop height and therefore may be more reliable for serial repeated measurements of FPPA. Additionally, the agreement in FPPA between the TJA and DVJ appeared to increase with maturity status, and thus; given the short duration of the tests it may be prudent to use both protocols for injury risk screening until prospective data become available examining the predictive ability of both tests to identify "at risk" athletes.

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Table 1. Participant characteristics per maturity group (mean ± *sd*)

Group	N	Age (yrs)	Standing height (cm)	Seated height (cm)	Body mass (kg)	Maturity offset (yrs)
Pre-PHV	17	11.9 ± 0.6	150.8 ± 10.2	75.8 ± 3.5	40.8 ± 8.8	-1.9 ± 0.7
Circa-PHV	15	13.8 ± 0.4	164.8 ± 8.5	82.4 ± 3.6	51.1 ± 8.2	0.0 ± 0.8
Post-PHV	25	16.7 ± 1.1	178.4 ± 5.0	89.7 ± 4.7	68.9 ± 7.6	2.7 ± 0.8

PHV = peak height velocity

Table 2. Mean (± *sd*) FPPA, where values <180º are indicative of medial knee displacement.

Group	TJA		DVJ	
	Left	Right	Left	Right
Whole group	173.4 ± 7.3[a]	172.7 ± 7.4[a]	179.2 ± 11.0	177.2 ± 11.7
Pre	172.3 ± 7.2	171.7 ± 6.8	178.1 ± 12.6	173.8 ± 12.3
Circa	172.5 ± 7.1	169.4 ± 6.4[b]	179.3 ± 10.6[c]	175.3 ± 10.4
Post	174.8 ± 7.5	175.3 ± 7.8	180.0 ± 10.5	180.7 ± 11.6

[a] *significantly different FPPA compared to the DVJ*
[b] *significantly different to FPPA-r in the TJA compared to the post-PHV group*
[c] *significantly different to FPPA-r in the TJA within the circa-PHV group*
DVJ = drop vertical jump
TJA = tuck jump assessment

Table 3. Correlation coefficients (r) for FPPA for each leg across both DVJ and TJA screening protocols

Group	DVJ-TJA (FPPA-r)	DVJ-TJA (FPPA-l)
Whole group	0.38[a]	0.38[a]
Pre-PHV	0.13	-0.21
Circa-PHV	0.44	0.68[a]
Post-PHV	0.43[a]	0.66[b]

[a] *significant relationship ($p < 0.05$)*

[b] *significant relationship ($p < 0.01$)*

DVJ = drop vertical jump

TJA = tuck jump assessment

FPPA-r = Frontal plane projection angle right leg

FPPA-l = Frontal plane projection angle left leg