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CONSISTENCY OF FIELD-BASED MEASURES OF NEUROMUSCULAR CONTROL USING FORCE PLATE DIAGNOSTICS IN ELITE MALE YOUTH SOCCER PLAYERS

--Manuscript Draft--

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Abstract:	Deficits in neuromuscular control during movement patterns such as landing are suggested pathomechanics that underlie sport-related injury. A common mode of assessment is measurement of landing forces during jumping tasks; however, these measures have been used less frequently in male youth athletes and reliability data is currently not available for elite male youth soccer players. The aim of this study was to determine the reliability of a field-based neuromuscular control screening battery using force plate diagnostics in this cohort. Twenty six pre-peak height velocity (PHV) and twenty five post-PHV elite male youth soccer players completed a drop vertical jump (DVJ), single leg 75% horizontal hop and stick (75%HOP) and single leg countermovement jump (SLCMJ). Measures of peak landing vertical ground reaction force (pVGRF), time to stabilisation (TTS), time to pVGRF, and pVGRF asymmetry were recorded. A test, re-test design was used to explore the within-subject inter-session reliability. In both groups, pVGRF during the 75%HOP and SLCMJ demonstrated acceptable reliability (CV ≤ 10%). Greater variability was evident in the DVJ test as indicated by higher CV values. Asymmetry values reported largely acceptable reliability (CV ≤ 10%). All other assessed variables, across all three protocols, exceeded the threshold for acceptable reliability in both groups (CV range = 13.8 - 49.7%). The results of this study suggest that pVGRF and asymmetry can be reliably assessed using a 75%HOP and SLCMJ in male youth soccer players. These measures could be utilized to support a screening battery for elite male youth soccer players and for test re-test comparison.

Response to Reviewers:	Dear reviewers, thank you for taking the time to review our manuscript. Your time, effort and expertise is highly appreciated. Additionally, your comments have contributed to enhancement of the paper raising some key and thought provoking points for consideration. In response to your specific comments we have outlined a point by point response below. To make it clearer and more time efficient we have completed the edits using track changes where indicated. Reviewer #1: Thank you for the opportunity to review this manuscript assessing reliability of important neuromuscular assessments in male youth athletes. The manuscript is well written but may be improved with the following comments. General: please check reference formatting for consistency and adherence to journal guidelines Author response: References have been amended in the text and formatted in the reference list in line with journal guidelines. Line 28 - What does pre-peak height velocity and post-pre height velocity elite male youth soccer players mean? Please clarify Author response: Due to the restrictions on word count in this section, the authors feel this is not possible as it will detract from providing an overview of the key findings from this study. Peak height velocity is generally a well-regarded term within paediatric literature but we appreciate it may not be familiar for all readers. In line with one of the later comments below we have added an operational definition with the main body of the manuscript. Line 49 - very long opening sentence Author response: The sentence has been re-worded Line 55 - check spacing Author response: Spacing error amended Line 58-67 - have any assessments been previously utilized in male youth athletes or only female (as this sentence implies)? Paragraph states the most comment mode of assessment is the DVJ - is this in male youth athletes or in general? If in youth, has reliability not been tested? The last sentence indicates single leg assessment should be considered and lists ICCs in youth athletes - was this for male, female, or both? This paragraph requires some clarification to better understand previous literature on what protocols have been utilized and assessed for reliability in youth female and male athletes. Author response: This paragraph has been edited to make it clearer for the reader which populations have been tested and areas required for further research to provide greater context. Lines 66-68 - if these have already been established in youth athletes, what is the gap in the literature? Author response: In line with the comment above, text has been added at the end of this paragraph to highlight the ‘gap’ in the literature that warrants further investigation. Lines 111-112 - please explain or provide an operational definition for pre-peak height velocity and post-PHV soccer players. Many readers may be unfamiliar with what a pre- and post-peak height velocity soccer player is.

Author response: Preceding text has been added to define peak height velocity for the readers.

Lines 124 - how exactly was sitting height measured, and what is the significance of this?

Author response: Text has been added to inform the reader of the procedure for measuring sitting height. This measurement is required to perform the regression equation of Miriwald et al. (2002) as has been included in the original manuscript.

Lines 130 - 131 - Which trial was used for analysis? Were there any criteria to signify a "bad" trial which would not have been analyzed?

Author response: In the experimental design section, there is stated text: ‘For the purposes of data collection, three trials were analyzed to reduce the influence of a learning effect.’ The criteria for what would be considered an appropriate jump is also provided in the procedures section under the sub-headings for each jump.

Lines 139 - onward - see above comment. Additionally - for all unilateral measurements, how was order of leg tested determined?

Author response: As indicated in the comment above, the instructions for what was considered an acceptable trial is described under each sub-heading and text describing that the mean of 3 trials was sued for analysis was included in the experimental design section. Regarding the order of leg testing, the randomization process was also applied in the same way as the other measures and to make this clearer for the readers; text has been included to state this in the experimental design section.

Lines 149 - onward - see above comment

Author response: Please see our responses above.

Lines 187-188 - were data assessed for normality?

Author response: We have inserted text at the start of the statistical analysis section to explain to the reader that the data was checked for normality

Lines 193-194 - what variables were compared with paired-samples t-tests?

Author response: All variables were checked for systematic bias using paired samples t-tests and this has been made clearer for the reader by stating ‘for all measures’ in the text.

Lines 217-218 - including more information about the two groups, what they represent, and why they were chosen should be explained in the introduction and study purpose so that the results and discussion are better understood.

Author response: The authors agree this is an important point. Text has been included in the final paragraph of the discussion to discuss trends in jump performance shown with advancing age, growth and maturation. Literature citing greater movement variability in younger athletes has also been included to provide a clearer context for the reader as to why it is important to examine the reliability of these measures in the two groups included in this study.

Lines 308-309 - why did subjects not retain the same testing order in a reliability study?

	Please address in a limitation sections Author response: Subjects retaining not retaining rank order does not necessarily indicate that the test is unreliable. In our discussion we have interpreted the ICC data and the relatively low scores, as this is a measure of how well subjects retain rank order across the two test sessions. In this section (last paragraph of the discussion) we have also included considerable discussion on why this mode of analysis may not be appropriate for an elite male youth soccer cohort. The reasons stated include: •Homogeneity of the participants •Performance clustering in the pre-PHV group due to players not achieving their peak growth spurt whereas the post PHV group are likely to be at different stages of physical development with some players further past the period of PHV than others; changing of rank order may be less frequent. Furthermore, we have suggested that subjects should consider using measures of within-subject variation (such as typical error / CV) as they may be more appropriate in this cohort. Practical applications - Please also include potential recommendations for future study. Author response: Text has been added at the end of this section to state 'Future research should examine if these measures can discriminate between injured and non-injured soccer players to determine their sensitivity in prospectively predicting injury risk.' Tables and Figures: Check consistency of significant figures in tables Author response: Tables have been amended and checked for consistency. Reviewer #2: General: This is useful information to the S&C coach and those responsible for athlete screening and injury prevention. My main comments center on firstly establishing that these tests are indeed valid - there is no mention of this and in particular how others have shown they can prevent injury etc. Also in the aim, make light of why you split the groups by APHV - why is this important? Author response: Thank you for your comments. Regarding the validity of the assessments, within the introduction there are references as to their previous use for identification of athletes with functional deficits and how they may be linked to injury risk. These include: •Deficits in neuromuscular control and aberrant movement patterns such as cutting, turning, and landing occurring frequently during game activities, (Price et al., 2004) are suggested pathomechanics (Alternton et al., 2009; Sugiomoto et al., 2015) that underlie sport-related injury (Gomes et al., 2008). •Poor attenuation of ground reaction forces during landing tasks may increase the risk of lower extremity injury (Lephart et al., 2002). •Measurement of dynamic stability may also provide useful information. "Time to stabilization" (TTS) calculations report deficits in postural control and reflex stabilization in subjects with functional ankle instability (Ross et al., 2005) and anterior cruciate ligament (ACL) deficiency (Webster and Gribble, 2010). Regarding the splitting of groups, in addressing the comments of reviewer 1, text has been included to highlight the effects of age and associated movement variability reported in jump-landing tasks. Abstract: Given that you are measuring reliability as an actual aim - all measures of reliability should be mentioned in here, not just the CV

Author response: Text has been included to highlight the key findings of the ICC reliability measures as well as the change in mean and CV's. Thank you for raising this point as on reflection we have decided to remove the TEE values from the tables for the following reasons. Typical errors were provided to show the level of error in raw units for each variable. However, as the different variables are measured in different units, direct comparison of the TE across variables is problematic. The CV expresses the random variation as a percentage, allowing for direct comparison between variables. Also, while TE is calculated from raw data it should be noted that the CV is calculated from log transformed data, which minimized any non-uniformity and heteroscedasticity (as per the Hopkins spreadsheet). Additionally, as an example of testing two boys of very different size (body mass) on a force measure, the CV is going to be much more useful than a TE. Therefore, based on these reasons we have removed the raw TE.

Introduction

Because this paper only addresses test reliability - the introduction should be used to explain their validity. Currently only methods to measure pathomechanics (and associated ICC's) are identified, but no mention has been made of whether they are actually any good practically. I think this is important to attract readership beyond those already familiar with the context of these tests

Author response: The authors agree demonstrating to the reader the validity of these tests is important. In responding to your general comments, we have highlighted where this has been included in the manuscript.

Ln. - 66 missing "of"

Author response: Text amended

What is the rationale for later splitting groups based on PHV - some justification must be mentioned here

Author response: As per our previous comments and addressing similar comments from reviewer 1, text has been included in the introduction to make this clearer for the reader.

Experimental approach

Ln 103 - surely three trials was for reliability assessment too and familiarisation was also used to avoid a learning effect

Author response: The authors agree this text may be misleading and as such been amended with removal of the text relating to a learning effect.

Is 10-min of dynamic stretching only, an appropriate warm-up? Presumably core temp would continue to rise during testing affecting results?

Author response: The dynamic warm up consisted of multiple whole body movements which were performed with minimal rest in between exercises, thus core temperature was also raised in conjunction with mobilisation of the key muscle and joint structures and movement preparation prior to testing. The text has been amended slightly here to state 'dynamic warm up' as opposed to 'dynamic stretching' as the former is more reflective of what was completed and the authors agree the term dynamic stretching may be misleading.

Not clear why you separated groups into pre and post PHV

Author response: As discussed earlier, text has been inserted into the introduction. Also, additional text has been inserted in the subject's section to further explain for the

	readers why this group separation was applied. Subjects What is "participant assent"? Author response: In situations when children who are minors (under 18) are included in research, specified regulations ensue that the assent of the child (participant assent) is obtained in addition to permission from the parent (parental consent). This is accepted practice for conducting research with paediatric populations and is required to meet ethical standards. I don't believe Table 1 is necessary - such a small and non-crucial data set can be easily added to the text Author response: table 1 has been removed and integrated within the text. All other table numbers have been amended. Statistical analysis Ln 192 - should read "95%" Author response: Text amended Discussion Match your aim with that in the intro - no mention of PHV in intro Author response: This has been amended in the introduction Ln 226 - impulse mentioned for first time and analysed. This needs to be stated in the methods Author response: Impulse was not measured during the current study. The authors agree this text may have been confusing for the readers; therefore we have inserted text to make it clearer that the reference to impulse relates to the work of Stålbom et al. (2007) and included an additional citation. Ln 227 - "0" missing from SEM Author response: Text amended 258 - did you not account for this through the post PHV group though? Author response: This text relates to the preceding citation of the work of Colby et al. (1999) and Ross et al. (2009). Text has been included to state ‘in comparison to adult data’ to make this clearer for the reader.

CONSISTENCY OF FIELD-BASED MEASURES OF NEUROMUSCULAR CONTROL USING FORCE PLATE DIAGNOSTICS IN ELITE MALE YOUTH SOCCER PLAYERS

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Dear JSCR Editorial Manager,

Please accept this as the requested cover letter for the journal submission entitled **'CONSISTENCY OF FIELD-BASED MEASURES OF NEUROMUSCULAR CONTROL USING FORCE PLATE DIAGNOSTICS IN ELITE MALE YOUTH SOCCER PLAYERS'**

This manuscript is original and not previously published, nor is it being considered elsewhere until a decision is made as to its acceptability by the JSCR Editorial Review Board.

I am the corresponding author for this submission and my contact details can be found above. If you require any further information please do not hesitate to contact me.

Yours Sincerely

Paul J. Read

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CONSISTENCY OF FIELD-BASED MEASURES OF NEUROMUSCULAR CONTROL USING FORCE PLATE DIAGNOSTICS IN ELITE MALE YOUTH SOCCER PLAYERS

ABSTRACT

Deficits in neuromuscular control during movement patterns such as landing are suggested pathomechanics that underlie sport-related injury. A common mode of assessment is measurement of landing forces during jumping tasks; however, these measures have been used less frequently in male youth soccer players and reliability data is sparse. The aim of this study was to examine the reliability of a field-based neuromuscular control screening battery using force plate diagnostics in this cohort. Twenty six pre-peak height velocity (PHV) and twenty five post-PHV elite male youth soccer players completed a drop vertical jump (DVJ), single leg 75% horizontal hop and stick (75%HOP) and single leg countermovement jump (SLCMJ). Measures of peak landing vertical ground reaction force (pVGRF), time to stabilisation (TTS), time to pVGRF, and pVGRF asymmetry were recorded. A test, re-test design was used and reliability statistics included: change in mean, intraclass correlation coefficient (ICC) and coefficient of variation (CV). No significant differences in mean score were reported for any of the assessed variables between test sessions. In both groups, pVGRF and asymmetry during the 75%HOP and SLCMJ demonstrated largely acceptable reliability (CV ≤ 10%). Greater variability was evident in DVJ pVGRF and all other assessed variables, across the three protocols (CV range = 13.8 – 49.7%). ICC values ranged from small to large and were generally higher in the post-PHV players. The results of this study suggest that pVGRF and asymmetry can be reliably assessed using a 75%HOP and SLCMJ in this cohort. These measures could be utilized to support a screening battery for elite male youth soccer players and for test re-test comparison.

Key Words

Landing force, Injury, Screening

INTRODUCTION

The demands~~sport~~ of soccer impose~~s~~ high physiological demand and an inherent risk of injury due to frequent repetitions of movements that involve significant musculoskeletal forces and ~~to dampen high velocity~~ joint loads (10). Existing injury incidence data in elite male youth soccer indicates that injuries occur mainly in the lower extremities (71-80%) and are largely non-contact in nature, with a high proportion of ligament sprains occurring at the ankle and knee (26, 39). Deficits in neuromuscular control and aberrant movement patterns such as cutting, turning, and landing occurring frequently during game activities, (Price et al., 2004) are suggested pathomechanics (1, 47) that underlie sport-related injury (16).

Assessments of neuromuscular control have been analyzed previously in adults and female athletes ~~using a variety of methods,~~ including a predominance of jump-landing tasks using force plate diagnostics (18, 33, 34, 36, 45). In order to accurately assess neuromuscular control in male youth soccer players, there is a need for reliable and valid testing protocols (41). Currently in youth males, the most common mode of assessment is measurement of landing forces during a drop vertical jump (DVJ) (24, 25, 40). This~~, a~~ protocol has shown~~that possesses~~ strong reliability in male and female high school athletes (ICC range = 0.89 – 0.98) (40). However, single leg horizontal and vertical jumps should also be considered due to the type and frequency of related movements during game play. Strong test re-test reliability has also been reported for measures of concentric~~and the ability of the tests to reliably determine~~ peak force and power during a single leg vertical jump (ICC range = 0.88 – 0.97) in healthy teenagers ~~(ICC range = 0.88-0.97) in youth athletes~~ (5). Available data in male youth soccer players and assessments of landing force are sparse.

In addition to the quantification of landing forces, measurement of dynamic stability may also provide useful information. “Time to stabilization” (TTS) calculations report deficits in postural control and reflex stabilization in subjects with functional ankle instability (44) and anterior cruciate ligament (ACL) deficiency (50). TTS is the speed in which individuals stabilize within a pre-determined ground reaction force range upon landing (11, 45). Although TTS has been quantified from a variety of jump-landing tasks (11), the most common method is a single leg horizontal hop onto a force plate (3, 33, 43). Limited data is available in youth athletes, however, ground reaction force measures in adults during single leg horizontal hops appear to be more reliable than centre of pressure values (ICC range = 0.87-0.97 vs. 0.53-0.75) (6, 45). Strong within-session reliability has also been reported for both dominant (r = 0.82) and non-dominant (r = 0.87) limbs (33).

In-spite of this growing body of evidence, kinetic landing assessments have been utilized less often in paediatric male athletes. Poor attenuation of ground reaction forces during landing tasks may increase the risk of lower extremity injury (27). Practitioners utilizing such assessments for pre-participation screening require a greater understanding of their accuracy in this cohort. Previous research investigating the effects of age, growth and maturation on jumping tasks has shown a trend of increased performances with age (12, 37). However, variation across growth and maturation may also be evident (28, 37) and movement variability during jumping tasks is more evident in younger athletes (16). To the author's knowledge, no data currently exists to confirm the reliability of jump-landing kinetic assessments for male youth soccer players. ~~and~~ T~~t~~his paucity of literature does not permit accurate interpretation of results following intervention or deficit assessments relative to the typical error. Research is also required to examine the effects of maturation on these measures due to the likelihood of greater movement variability in younger players. Therefore, the aim of this study is to determine the within-subject reliability of a field-based neuromuscular control screening battery using force plate diagnostics in elite male youth soccer players at different stages of growth and maturation.

METHODS

Experimental Approach to the Problem

This study used a repeated measures design to determine the intersession reliability of a range of field-based neuromuscular control assessments. Participants were required to attend the club training ground on three occasions separated by a period of seven days. The first session was used to familiarize subjects with the test equipment and assessment protocols. In the second and third sessions, data was collected to determine test-retest within-subject variation for the reliability study. Three different force plate diagnostic assessment protocols were used, including: a drop vertical jump (DVJ), a single leg 75% horizontal hop and stick (75%HOP) and a single leg countermovement jump (SLCMJ). A 10-minute standardized dynamic warm up was completed prior to each session. ~~consisting of dynamic stretching.~~ The order of testing was randomized using a counterbalanced design to reduce the potential for an order effect. This randomization process was also applied for all unilateral jumps to determine the order of which leg was tested first. For the purposes of data collection, three trials were analyzed and ~~to reduce the influence of a learning effect.~~ o~~O~~ne minute of recovery was allowed between trials based on previous recommendations (11). Testing was completed at the same time on each day, and participants were asked to wear the same training kit and footwear, and refrain from strenuous exercise at least 48 hours prior to testing. Subjects were also asked to eat according to their normal diet and avoid eating and drinking substances other than water one hour prior to each test session.

Subjects

Participants were grouped as either pre- or post-peak height velocity (PHV) which has been defined as the maximal rate of growth during the adolescent growth spurt (29). This group separation was applied to examine if a players stage of maturation affects the reliability of the test measures included in this study due to previous research indicating greater movement variability is present in younger children (15). Twenty five pre-PHV (age 11.93 ± 0.43 yr; height 151.40 ± 4.84 cm; body mass 41.05 ± 5.62 kg; maturity offset -2.34 ± 0.41 yr) and twenty five post-PHV (age 17.26 ± 0.69; height 178.22 ± 5.47; body mass 72.27 ± 6.93 kg; maturity offset 2.91 ± 0.81 yr) ~~Twenty five pre-PHV and twenty five post-PHV~~ youth soccer players from the academy of a professional English Championship soccer club volunteered to take part in the study. ~~Subject characteristics are provided in table 1~~. Subjects were familiar with regular performance evaluations and none of the players reported injuries at the time of testing. 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.

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). Seated height was measured with subjects sat on a box and their back against an upright stadiometer. The height of the box was then subtracted to provide the recorded value. Using anthropometric measures (age, body mass, standing height and sitting height, biological maturation was measured utilising the regression equation of Mirwald et al. (32). The equation has previously been validated for boys with a standard error of estimate of 0.57 years (Mirwald et al., 32).

Drop Vertical Jump (DVJ)

Participants were positioned on top of a box at a height of 30 cm. Instructions were to drop directly down with no vertical elevation onto two separate force plates (Pasco, Roseville, California, USA) positioned 8 cm apart. Upon ground contact, players immediately performed a maximum vertical jump aiming to jump as high as possible and then land on the plates and stick the landing as per previous guidelines (34. Hands were freely available to replicate a natural jump-landing position (34, 40). Only the data from the first landing was used for subsequent analysis.

Single leg 75% Horizontal Hop and Stick (75%HOP)

A tape measure was marked out to a three metre distance on a horizontal line with the zero cm mark positioned in line with the centre of a force plate (Pasco, Roseville, California, USA). Participants began by standing in line with the force plate on the designated test leg; hands on their hips and toe in line with a distance marker on the tape measure representing 75% of their predetermined maximal single leg hop and stick performance. Instructions were to hop forward onto the force plate, landing on the same leg with the hands remaining on their hips throughout. Players were required to stick the landing and hold for a period of five seconds, remaining as still as possible without any other body part touching the floor (11).

Single Leg Counter Movement Jump (SLCMJ)

Participants stood on a force plate (Pasco, Roseville, California, USA) in a unilateral stance with their hands on their hips and the opposite hip flexed at 90° to ensure minimal contributions from the contralateral leg. Instructions were to jump as high as possible using a countermovement by dropping to a self-selected depth and then immediately triple extending at the ankle, knee and hip in an explosive concentric action. On ground contact, subjects were required to stick the landing and hold for a period of five seconds remaining as still as possible. Bending of the knees whilst airborne was not permitted, and hands remained in contact with hips throughout the test (11).

Force Plate Variables

Kinetic landing data captured from the force platform included: peak vertical ground reaction force (pVGRF) recorded in the first 100ms following ground contact, time to pVGRF, and pVGRF asymmetry during for all tests. A cut-off point of 100ms was used to determine pVGRF due to the reported timing of non-contact injuries which occur within a similar time-frame following initial ground contact (22). Forces experienced after this point are unlikely to contribute to acute injury risk and were therefore not included in the analysis. In the SLCMJ and 75%HOP protocols, time-to-stabilisation (TTS) was also quantified from the vertical force vector. Vertical TTS was calculated as the time taken from ground contact to the first point when the vertical force component reached and stayed within 5% of body weight for a period of one second (11, 14). The point of ground contact was then subtracted from this value in accordance with previous guidelines (11). For the DVJ and 75%HOP protocols, initial contact was defined as the point when vertical ground reaction force first exceeded 10 N. In the SLCMJ, the same criteria were used to determine initial contact following the preceding propulsive and flight phases. All data were recorded at a sampling rate of 1000 Hz and filtered through a fourth-order Butterworth filter. A cut-off frequency of 18, 21, and 26 Hz was used for the SLCMJ, DVJ, and 75%HOP respectively.

Asymmetry Calculation

To quantify asymmetry, the percentage difference between the highest and lowest performing limb was used. The value obtained is expressed as the absolute percentage of performance achieved using the higher performing limb as the reference (see equation 2).

$$\text{Asymmetry \%} = \text{ABS}((\text{lowest performing limb} - \text{highest performing limb}) / \text{highest performing limb} * 100)$$

$$\text{\% of Performance achieved} = 100 - \text{\% Asymmetry}$$

[equation 2]

Statistical Analysis

The data was checked for normality and descriptive statistics~~The mean and standard deviations~~ for each test were calculated across the two testing sessions. To determine systematic bias between trials, a series of paired samples t-tests were used for all measures with a p value ≤ 0.05 indicative of a significant difference between the two trials. Within-subject variation was determined using mean coefficients of variation (CV %). Further reliability statistics included: change in mean and intra-class correlation coefficient (ICC). 95% confidence intervals (95~~0~~% CI) were used and all reliability data was computed through Microsoft Excel® 2010 using a freely available spread sheet (20). Paired samples t-tests were processed using SPSS ® (V.21. Chicago Illinois).

RESULTS

Descriptive statistics and all reliability measures calculated for each test are displayed in tables 1 and table 2 for pre- and post-PHV groups respectively. No significant differences were reported for the test variables when the mean scores of the two test trials were analyzed using a series of paired samples t-tests ($P > 0.05$).

************** *Insert tables 1 and 2 near here* ***************

Following the analysis of all variables, measures highlighted with acceptable CV values (≤10%) (8) were then further investigated to determine the reliability of lower-limb asymmetry (table 3). In both groups, all measures reported acceptable CV values (≤10%) with the exception of 75%HOP pVGRF in pre- (CV = 11.8%) and post-PHV (13.2% post-PHV) cohorts.

************* *Insert table 3 near here* ****************

DISCUSSION

The current study assessed the reliability of a field-based neuromuscular control screening battery using force plate diagnostics in elite male youth soccer players who were either pre- or post-PHV. In both groups, pVGRF in the 75%HOP and SLCMJ demonstrated acceptable reliability (CV ≤ 10%). However, greater variability was evident in the DVJ test as indicated by higher CV values. Irrespective of test protocol, variability was more pronounced in the pre-PHV group than the post-PHV cohort. Asymmetry values for the measures identified (CV ≤ 10%) were also analyzed and reported largely acceptable reliability (CV ≤ 10%). The within-subject variance of all other assessed variables, across all three protocols, exceeded the threshold for acceptable reliability (CV >10%) in both groups.

In both groups, pVGRF was the most reliable kinetic measurement reflected by the lowest CV%. These findings are commensurate with Cordova et al. (7) who reported excellent reliability values (ICC = 0.94; SEM = 0.003% body weight) during a SLCMJ onto a force plate. Other studies have also reported high within-session reliability in adults for pVGRF during a single leg hop and stick (ICC = 0.82 to 0.87) (3) and inter-session reliability of a single leg horizontal drop jump (CV = 5.71) (46). Conversely, vertical impulse (a measure comprised of both force and time) was shown to display greater test re-test variation (8.28%) (46). In the present study, while not a direct measure of impulse, time to pVGRF also showed higher CV values indicating greater within-subject variation for these metrics in male youth soccer players.

In this study, pVGRF in both the SLCMJ and 75%HOP tests demonstrated lower within-subject variation than the DVJ. In school children, strong reliability for measures of pVGRF force at landing (ICC = 0.89), and take-off (ICC = 0.98) has been reported (40). In the present study, lower reliability was displayed in the pre-PHV group which may be indicative of reduced skill levels, and immature pre-frontal motor cortex activation for cognitive control resulting in greater variation in the execution of motor control tasks (4). Additionally, increased jumping skill has been associated with an enhanced ability to absorb landing forces (38). As males progress through adolescence they appear to display an increased ability to attenuate landing forces, possibly due to the presence of the neuromuscular spurt (40). Conversely, younger children appear to land with greater knee and hip extension, which combined with heightened muscle co-contraction upon impact, will lead to higher pVGRF (9, 48). Supporting this notion, lower pVGRF related to body mass during the breaking phase of a DVJ have been reported in adults versus boys (25). This may be due to more efficient stretch reflex utilization and greater levels of muscle activation prior to landing and during the breaking phase of the jump (24). Data also shows that as children mature they become more reliant on supra-spinal feed forward input and short latency stretch reflexes (28). Cumulatively, the combination of movement inefficiency and higher landing forces may provide a rationale for the greater variability in pVGRF within the pre-PHV soccer players in this study.

During the 75%HOP and SLCMJ, high CV's were reported for TTS in both groups. These values indicate large within-subject variance and thus, caution should be applied when using this measurement in male youth soccer players. Obtaining high reliability for repeated trials during tasks requiring dynamic postural stability is difficult (11). Single leg jumping and landing activities that rely on reflexive muscle responses, proprioceptive and kinaesthetic feedback will typically utilise a range of movement strategies and therefore increase variability (11, 51). No data is available to compare the results of this study to those of similar populations, however, reliability statistics in adults suggest strong test re-test comparisons in single leg hop tasks (ICC = 0.87 – 0.97) (6, 45). A plausible explanation for the high CV% in this study in comparison to adult data could be age-related factors, such as, growth, maturation and skill. Previous literature has suggested that maturation of the neurological, visual, vestibular and proprioceptive systems may lead to enhanced performance during single leg balancing tasks (31). Also, younger subjects demonstrate greater postural sway during single leg balance manoeuvres which may compromise stability (31). Thus, measures of reflex stabilization may be subject to greater variability in male youth soccer players.

Task demands are another factor which may explain the differences in reported reliability from this study and those of previous investigations. In the present study, two single leg landing assessments were used to provide data for both horizontal and vertical jumping tasks. Conversely, the aforementioned studies used horizontal tasks only and a standardised distance from the force plate of either leg length (6), or an arbitrary distance of 70 cm (45). The utilization of anthropometric measures or standardised distances may subsequently over or under-estimate an individual's performance. For example, an athlete with short legs may demonstrate a reduced TTS due to the relatively shorter hopping distance required. However, during a maximal single leg hopping task, the same athlete may be capable of much greater jump distances than that of their leg length. These abilities are likely to be replicated under conditions of competitive soccer match play; thus, an individual's inherent risk of injury is likely a product of how far they can jump and how well they can attenuate the resultant forces upon landing.

The methods of calculating TTS could also account for inconsistencies with the available literature. In the current study, TTS was measured based on previous recommendations (11, 14). Conversely, Colby et al. (6) and Ross et al. (45) used both anterior-posterior and medio-lateral force vectors and a static hold of twenty seconds, scanning the components from the last two windows of the last 10s (i.e. at 10-15s and 15-20s), and the smallest ground reaction force range was accepted as the optimal range variation (43). This method, while displaying sound reliability, raises concerns of ecological validity when screening male youth soccer players. For example, if young soccer players are required to spend up to 20 seconds standing still on a force plate, they are likely to demonstrate greater postural sway, thus affecting their ground reaction force range. The shorter recording period of five seconds used in this study as opposed to 20 seconds (43) also has implications for testing a large number of athletes, particularly youth athletes who may demonstrate lower levels of concentration.

Despite their frequency of use, limited data is available to report the reliability of limb asymmetry statistics during unilateral jumping tasks. One available study in ACL patients determined the 'limb symmetry index' for a range of hopping based tests using ICC and standard error of measurement (ICC = 0.82 – 0.93; SEM = 3.04 – 5.09) (42). The authors assessed differences between the injured and non-injured leg, whereas, previous research has analyzed the difference between the dominant and non-dominant legs although no reliability data was reported (2, 30). In high school male and female soccer players, strong reliability of force production and attenuation measures has been shown (ICC > 0.97), however, specific outcome measures were not reported (17). The present study showed acceptable reliability values for most of the measures included and calculated asymmetry using the highest versus lowest performing leg. This accounts for neuromuscular inhibition which can occur following an injury to a specific limb (13, 35) and the requirement to jump and land repeatedly on both legs during a soccer competition. No data is available in youth male soccer players to compare the findings of this study; further investigations are needed to examine the reliability of asymmetry values using the aforementioned methods during a variety of jump-landing tasks.

A number of the variables measured in this study demonstrated low ICC statistics. It has been suggested previously that an ICC value > 0.75 is acceptable and values below this provide inadequate reliability (23). However, re-test correlations measure how closely the values of two trials track each other specific to each individual and the reproducibility of the rank order of subjects during the re-test (19). Low values indicate that subjects did not retain their order during the re-test. Furthermore, a homogenous sample will also likely demonstrate a low value (19). The subjects in this study are reflective of a homogenous sample and this provides a plausible explanation for lower ICC values than those in other studies. Specifically, a number of the test variables in this study reported lower ICC values in the pre-PHV players. Due to their status as prepubescent athletes, performance levels may be more clustered as they have not yet experienced their peak growth spurt; the possibility of players changing their rank order is high. The post-PHV players were likely at different stages of physical development with some players further past the period of PHV than others; changing of rank order may be less frequent, as evidenced by predominantly higher ICC values.

PRACTICAL APPLICATIONS

Reliability data is now available for a field-based battery of neuromuscular control assessments using force plate diagnostics to screen male youth soccer players for potential injury risk. Practitioners can benefit from this data by selecting from the wide range of assessments available in the literature by considering their reproducibility as a basis for test re-test comparison. Furthermore, using the reliability statistics derived from this study, the smallest worthwhile change can be determined by calculating the between-subject standard deviation for each test and multiplying this number by 0.2 or

0.5% of the CV (21). If this value is within the error range (CV %) reported by the test, then it can be deemed reliable for use (49). Also, coaches applying interventions to reduce injury risk can accurately establish if the measured effects are reflective of a true change in performance.

Acceptable reliability values were reported for a variety of measures. In both the pre and post-PHV groups, pVGRF in both the 75%HOP, and SLCMJ demonstrated acceptable reliability (CV ≤ 10%). These variables should be considered reliable for assessing elite male youth soccer players. However, greater within-subject variation was evident during the DVJ for all recorded variables; thus, caution should be applied when utilizing these protocols in this cohort. Overall, the results of this study suggest that pVGRF and asymmetry can be reliably assessed using a 75%HOP and SLCMJ in male youth soccer players. These measures could realistically be utilized to support a screening battery for elite male youth soccer players and for test re-test comparison. Future research should examine if these measures can discriminate between injured and non-injured soccer players to determine their sensitivity in prospectively predicting injury risk.

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Table

Table 1 Pre-PHV group mean results and reliability statistics for all test measures

Test Variable	Mean Test 1	Mean Test 2	Change in mean	ICC	CV% (95% CI)
75% HOP pVGRF (N)	1642 ± 297	1617 ± 253	-24.9 ± 254.65	0.62	10.2 (8.5 - 13.2)
75% HOP TTS (s)	1.740 ± 0.709	1.963 ± 0.642	0.223 ± 0.789	0.25	43.6 (35.6 - 56.6)
75% HOP time to pVGRF (s)	0.022 ± 0.005	0.023 ± 0.006	0.001 ± 0.006	0.57	20 (16.6 - 25.3)
DVJ pVGRF (N)	890 ± 217	844 ± 235	-45.59 ± 227.69	0.50	20.5 (17.1 - 25.8)
DVJ time to pVGRF (s)	0.044 ± 0.022	0.045 ±0.024	0.001 ± 0.02	0.54	49.7 (40.6 - 64.4)
SLCMJ PVGRF (N)	1221 ± 170	1251 ± 245	30.92 ± 194.65	0.59	10.1 (9.1 - 14.1)
SLCMJ TTS (s)	1.226 ± 0.648	1.438 ± 0.508*	0.212 ± 0.614	0.37	39.2 (31.9 - 51.9)
SLCMJ time to pVGRF (s)	0.067 ± 0.043	0.054 ± 0.023	-0.012 ± 0.039	0.64	33.3 (28.6 - 48.9)

Note: pVGRF = peak vertical ground reaction force; TTS = time to stabilization; 75%HOP = 75% horizontal hop and stick

DVJ = drop vertical jump; SLCMJ = single leg countermovement jump; PHV = peak height velocity

Table 2 Post-pubertal group mean results and reliability statistics for all test measures

Test Variable	Mean Test 1	Mean Test 2	Change in mean	ICC	CV% (95% CI)
75%HOP pVGRF (N)	2825 ± 551	2755 ± 539	-70.92 ± 230.73	0.91	6.1 (5.1 - 7.8)
75% HOP TTS (s)	1.160 ± 0.384	1.326 ± 0.434	0.165 ± 0.544	0.09	35.2 (28.4 - 46.5)
75% HOP time to pVGRF (s)	0.027 ± 0.011	0.029 ± 0.009	0.001 ± 0.010	0.62	22.5 (18.3 - 29.2)
DVJ pVGRF (N)	1781 ± 450.96	1751 ± 462	-29.66 ± 313.39	0.76	13.8 (11.6 - 16.9)
DVJ time to PF (s)	0.056 ± 0.023	0.052 ± 0.018	-0.004 ± 0.016	0.77	23 (19.4 - 28.2)
SLCMJ pVGRF (N)	2369 ± 396	2372 ± 391	-0.03 ± 302.24	0.75	9.5 (8.1 - 11.5)
SLCMJ TTS (s)	1.033 ± 0.435	1.112 ± 0.462	0.079 ± 0.631	0.08	48.4 (40.3 - 60.3)
SLCMJ time to pVGRF (s)	0.060 ± 0.019	0.057 ± 0.018	-0.002 ± 0.013	0.72	21.8 (18.4 - 26.8)

Note: pVGRF = peak vertical ground reaction force; TTS = time to stabilization; 75%HOP = 75% horizontal hop and stick

DVJ = drop vertical jump; SLCMJ = single leg countermovement jump; PHV = peak height velocity

Table 3 Pre- and Post PHV group asymmetry mean values and reliability statistics expressed as % of performance achieved

Group	Test variable	Mean test 1	Mean test 2	Change in mean	ICC	CV % (95% CI)
Pre-PHV	SLCMJ pVGRF	88.08 ± 7.18	86.34 ± 7.70	-1.74 ± 11.63	-0.22	10.9 (8.7 - 14.2)
	75%HOP pVGRF	86.63 ± 10.39	90.68 ± 10.21	4.05 ± 13.21	0.17	11.8 (9.2 - 14.5)
Post-PHV	SLCMJ pVGRF	89.84 ± 7.71	88.53 ± 8.78	-1.38 ± 9.78	0.25	8.6 (6.8 - 11.6)
	75%HOP pVGRF	84.15 ± 9.51	77.09 ± 10.60	-1.80 ± 14.00	0.01	13.2 (10.1 - 14.5)

Note: pVGRF = peak vertical ground reaction force; SLCMJ = single leg countermovement jump; 75%HOP = 75% horizontal hop and stick;

PHV = peak height velocity