

Research article

## Intra- and Inter-Rater Reliability of the Modified Tuck Jump Assessment

Azahara Fort-Vanmeerhaeghe<sup>1,2</sup>✉, Alicia M. Montalvo<sup>3</sup>, Rhodri S. Lloyd<sup>4,5,6</sup>, Paul Read<sup>7,8</sup> and Gregory D. Myer<sup>9,10,11,12</sup>

<sup>1</sup> School of Health and Sport Sciences (EUSES) Universitat de Girona, Salt, Spain; <sup>2</sup> Blanquerna Faculty of Psychology, Education Sciences and Sport (FPCEE), Universitat Ramon Llull, Barcelona, Spain; <sup>3</sup> Florida International University, Nicole Wertheim College of Nursing and Health Sciences, Department of Athletic Training, Miami, FL; <sup>4</sup> Youth Physical Development Unit, Cardiff Metropolitan University, Cardiff, Wales; UK; <sup>5</sup> Sport Performance Research Institute New Zealand (SPRINZ), Auckland University of Technology, New Zealand; <sup>6</sup> Centre for Sport Science and Human Performance, Waikato Institute of Technology, New Zealand; <sup>7</sup> School of Sport, Health and Applied Science, St Mary's University, London, UK; <sup>8</sup> Research Department, Aspetar Sports Medicine Hospital, Doha, Qatar; <sup>9</sup> Division of Sports Medicine, Cincinnati Children's Hospital Medical Center, Cincinnati, OH; <sup>10</sup> Department of Pediatrics, College of Medicine, University of Cincinnati, Cincinnati, OH; <sup>11</sup> Sports Health and Performance Institute, Ohio State University, Sports Medicine, Ohio State University Medical Center, Columbus, OH; <sup>12</sup> Micheli Center for Sports Injury Prevention, Waltham, MA, USA;

### Abstract

The Tuck Jump Assessment (TJA) is a clinician-friendly screening tool that was designed to support practitioners with identification of neuromuscular deficits associated with anterior cruciate ligament injury. This study aimed to evaluate the inter- and intra-rater reliability of the modified scoring (0 to 2) TJA to add an additional range of objectivity for each criterion. A total of 24 elite youth volleyball athletes (12 males and 12 females) were included in this study. Each participant's recorded performance of the TJA was scored independently by two raters across ten criteria using the modified scale. The two raters then scored the same videos one week later. Another investigator who was blind to the identity of the raters analyzed the scores from both raters for each participant. Kappa coefficient (*k*) and percentage of exact agreement (PEA) for both intra- and inter-rater reliability were analyzed for each item. Intraclass correlation coefficients (ICC) were calculated to determine intra- and inter-rater reliability of the modified TJA total score. Intra- and inter-rater *k* was good to excellent for most items (0.65-0.91). Average PEA between the two raters and two sessions ranged from 83.3 to 100% in all scored items. The ICC for the total score was excellent in both inter- and inter-rater correlations (0.94-0.96). This research demonstrated that the modified version of the TJA predominantly shows good to excellent intra- and inter-rater reliability in all analyzed criteria.

**Key words:** repeatability, ACL, screening tools.

### Introduction

Lower extremity pathomechanics during high impact activity, such as directional changes, landing, and deceleration, have been associated with increased risk of injury in athletes playing team sports (Griffin et al., 2006; Hewett et al., 2005), especially in young female athletes (Myer et al., 2013). One of the most common lower extremity high risk movements described in the literature is dynamic valgus, which is associated with anterior cruciate ligament (ACL) injury (Hewett et al., 2005) and, patellofemoral pain (Myer et al., 2010). Female athletes exhibit a

4- to 6-fold increase in incidence of ACL injuries compared to male athletes (Arendt and Dick, 1995). The mechanism underlying this gender disparity in ACL injury incidence is likely multi-factorial (Elliot et al., 2010; Hewett et al., 2010). Intrinsic risk factors for ACL injury include anatomic, hormonal, and neuromuscular abnormalities (Griffin et al., 2006). Of these factors, aberrant neuromuscular control is modifiable and thus provides direction for targeted neuromuscular training with high-risk individuals (Hewett et al., 2010).

Video analyses have revealed four common motor performance components that potentially contribute to non-contact ACL injury in female athletes during landing (Hewett et al., 2010): 1) knees collapse medially upon landing, 2) the injured knee is near full extension at landing, 3) most if not all of the athlete's weight is supported on a single limb, and 4) the trunk tends to be flexed laterally at landing. While these same components are observed in male athletes, they are more pronounced in female athletes (Alentorn-Geli et al., 2009; Hewett et al., 2010). Moreover, related to these components of ACL injury are four neuromuscular imbalances (Hewett et al., 2010), namely; 1) an increased reliance on frontal plane control compared to sagittal plane control (dynamic valgus or ligament dominance) (Ford et al., 2003; Hewett et al., 2005), 2) a quadriceps dominant strategy to stabilize the knee joint with lower contributions from the hamstring muscles (quadriceps dominance) (Myer et al., 2007), 3) greater strength, coordination, and balance in the dominant limb (leg dominance) (Hewett et al., 2005), and 4) decreased proprioception and stability of the trunk (trunk dominance) (Hewett and Myer, 2011). Though research is scarce, the relationship between neuromuscular risk factors and knee injuries has also been described in young male athletes (Read et al., 2016a).

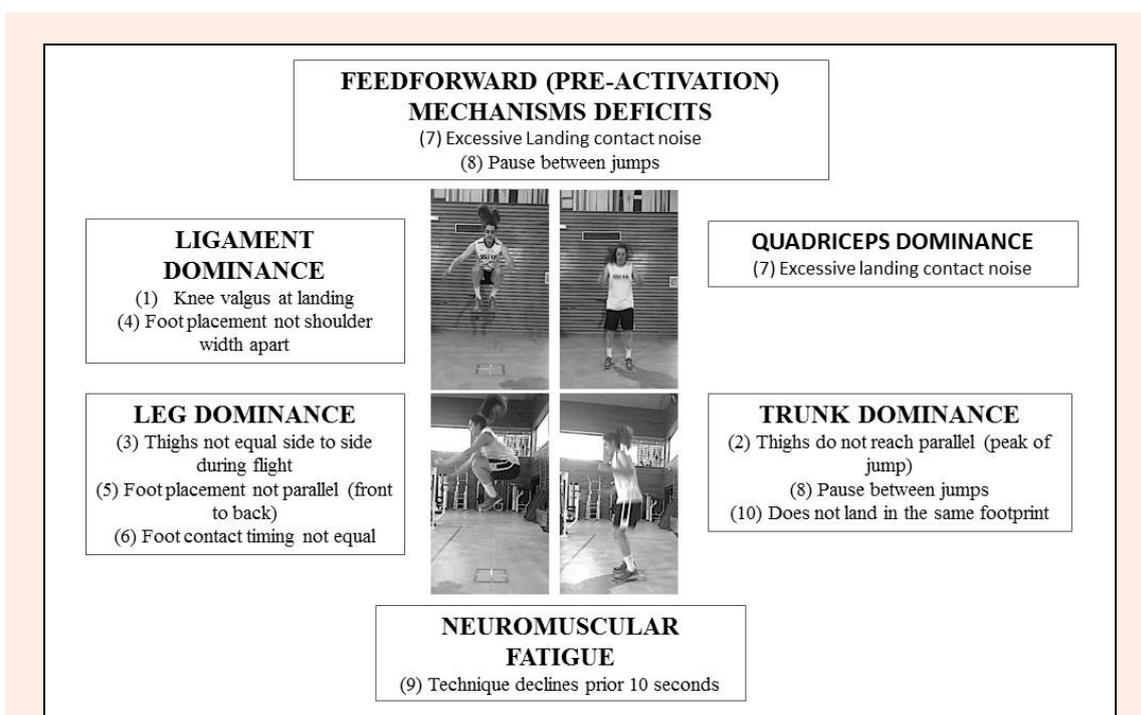
Traditionally, kinematics have been assessed by 3-dimensional (3-D) motion capture during different sport-specific movements. The most commonly measured actions are unilateral and bilateral drop jumps (Hewett et al., 2016) and changes of direction (Almonroeder, Garcia and

Kurt, 2015). Assessment of kinematic variables using 3-D motion capture, such as knee valgus during jump-landing tasks, provides both valid and reliable indicators of ACL injury risk (Hewett et al., 2005). However, 3-D motion capture is expensive and requires extensive training and expertise; therefore, it is not practical for use in most clinical settings (Krosshaug et al., 2016). Recent research has focused on the development of clinical tools that provide more cost-effective and user-friendly methods of lower extremity biomechanical screening compared to laboratory methods (Crossley et al., 2011; Fox et al., 2016; McCunn et al., 2016; Padua et al., 2011). The most common tools are the single-leg squat (Crossley et al., 2011; Stensrud et al., 2011), single-leg (Stensrud et al., 2011) and bilateral (Ekegren et al., 2009; Hewett et al., 2005; Myer et al., 2007; Padua et al., 2011) drop vertical jump, and continuous tuck jumps (Myer et al., 2008b). The single leg squat is a functional task that does not mimic high intensity, sport-specific actions characteristic of knee injury mechanisms. Whereas, the single-leg and two-leg vertical drop jump only assess the landing phase of a single loading task, which may limit assessment of repeated jump scenarios to identify multiple characteristics of sport-specific deficits. Conversely, the tuck jump assessment (TJA) (Herrington et al., 2013; Myer et al., 2008b; Stroube et al., 2013) evaluates landing technique flaws during a maximal repetitive plyometric activity (Myer et al., 2008a) where landing heights are reflective of each individual's jumping ability and therefore forces are equivalent to those regularly experienced during sporting actions. Furthermore, the repeated nature of the tuck jump assessment provides an indication of reactive strength capabilities and some inherent perturbation, more accurately reflecting the movement demands and high-

risk mechanics involved in competition (Read et al., 2016b).

The TJA consists of continuous maximal height tuck jumps for ten seconds and involves the analysis of ten quantitative and dichotomous items. These ten items are used to assess the four aforementioned neuromuscular imbalances related to ACL injury (ligament, quadriceps, leg, and trunk dominance) (Hewett et al., 2010). Moreover, this test also includes the assessment of fatigue (Borotikar et al., 2008) and diminished feed-forward, or anticipatory, response (Riemann and Lephart, 2002) as neuromuscular imbalances that may exacerbate lower extremity pathomechanics during a high impact activity (Figure 1).

Participants are scored with a '0' if they meet the specified criteria and with a '1' if they do not meet the specific criteria. While the TJA is clinically useful (Myer et al., 2008b; Herrington et al., 2013), there are limitations associated with the traditional scoring scheme. The TJA includes non-specific information concerning training and background of the scoring criteria for raters, especially for those raters unfamiliar with the assessment. In addition, the current dichotomous scoring system does not allow the rater to evaluate the severity of dysfunction within items. This limitation makes it difficult to detect both reductions in high-risk movement patterns resulting from neuromuscular training and increases in high-risk movement patterns as a result of fatigue, injury or growth disturbances. Intuitively, by changing the scoring system from the original scale (0-1) to a modified scale (0-2) it may be possible to provide more objective information about an individual's risk of ACL injury. To test this hypothesis, it is necessary to first establish the reliability of this modified scoring scheme. Therefore, the main



**Figure 1.** The tuck jump test consists of continuous maximal height tuck jumps for ten seconds and analyzes ten items that are related with the major neuromuscular risk factors associated with non-contact LCA injury: Ligament dominance, Quadriceps dominance, Leg dominance, Trunk dominance, Feed-forward mechanisms deficits and Neuromuscular fatigue.

**Table 1.** Mean ( $\pm$ standard deviation) of age, body mass, stature, sport experience and % body fat of the studied sample.

|                                       | Females (n=12) | Males (n=12) | Total (n=24) |
|---------------------------------------|----------------|--------------|--------------|
| Age (years)                           | 15.70 (.94)    | 15.79 (.87)  | 15.79 (.63)  |
| Years of peak Height Velocity*        | 3.33 (.63)     | 2.33 (.93)   | 2.85 (.93)   |
| Body mass (kg)                        | 63.30 (6.36)   | 73.1 (6.95)  | 68.03 (8.22) |
| Height (m)                            | 1.75 (.07)     | 1.88 (.06)   | 1.81 (.09)   |
| BMI ( $\text{kg}\cdot\text{m}^{-2}$ ) | 20.72 (2.26)   | 20.79 (1.89) | 20.76 (2.05) |
| Training experience (years)           | 3.77 (1.59)    | 2.54 (1.61)  | 3.15 (1.69)  |

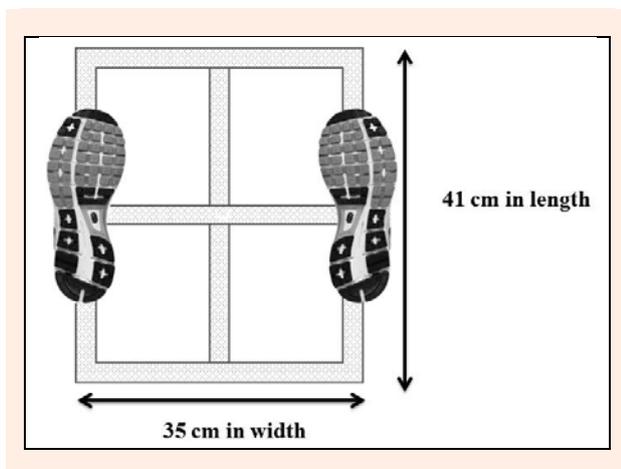
\* Estimation of biological age (Mirwald et al., 2002)

objective of this study was to evaluate the inter- and intra-rater reliability of the TJA with modified scoring.

## Methods

### Participants

Twenty-four elite youth volleyball athletes (12 males and 12 females) were recruited from a high performance center in Spain and were included in this study. Study participants were excluded if they presented with any injury (overuse or acute) at the time of testing. Table 1 provides subject characteristics. All of the subjects were actively participating in a four-year professional development program at the time of the study. In addition to a weekend game, subjects had 8-10 training session per week, which each lasted approximately 120 min. Written informed assent and consent were obtained from study participants and their parents. The Sport Council Ethics Committee approved the study.



**Figure 2.** Rectangles marked on the floor to perform the Tuck Jump Test. Both feet are placed in the middle of the square.

### Procedures

#### Test Procedures

A week before data collection, study participants were familiarized with the testing procedures and anthropometric measurements were taken. Study participants were shown a video presentation and a live demonstration of correct tuck jump technique. The video consisted of representative images from frontal and sagittal views of a tuck jump. The TJA consists of continuous maximal height tuck jumps for ten seconds. Participants were instructed to place their feet in the middle of the rectangle marked on the floor. This square consisted of four smaller rectangles (Figure 2). In addition, basic instructions given

about how to carry out the test included information on lifting the knees to hip height and attempting to land on the same footprint with their feet shoulder width apart (Myer et al., 2008b; 2011). Participants were then allowed to ask questions to clarify their understanding of what was required in order to correctly perform the test and were provided 3-5 practice trials to ensure accurate interpretation of the tuck jump

On the day of testing, all participants completed the same ten-minute neuromuscular warm-up, consisting of: multidirectional movements combined with strength and dynamic stretching exercises and maximal and progressive intensity displacements including change of directions, jumps, and acceleration/deceleration movements. Participants were allowed to practice no more than two trials of the tuck jump prior to data collection. Following the warm-up, each participant carried out continuous tuck jumps on the designated location for ten seconds after receiving again basic instructions about how to complete the test. The performance of each test session was recorded using two cameras (iPad 5 and/or iPhone 6, Apple, Inc., USA) with height marked at the athlete's waist. One camera was aligned three meters away in the sagittal plane and the other was aligned three meters away in the frontal plane. To allow visible tracking of the knees, participants were required to wear shorts with the hem at approximately mid-thigh.

#### Scoring

Two raters participated in this study (AB, SM). Both raters were certified strength and conditioning coaches with over five years of clinical experience each and previous training and experience with scoring the modified TJA from video replay. Each participant's recorded performance of the tuck jump test was scored independently across ten criteria by the two raters. The individual criteria along with the scoring sheet are shown in Figure 3 and Table 2. If participants failed to meet the criteria on any given repetition described in Table 2, then they scored one or two (magnitude of the score). If participants met the criteria, then they scored zero for the respective category. In order for a movement to be considered dysfunctional, the specific technique error had to appear two or more times during the ten-second test. As in the original tuck jump test, a lower score (e.g. reduced identified deficits) indicated a better performance.

When scoring performance, each trial was viewed in both planes (sagittal and frontal views). Free video software (Quicktime Player 7.6.6.) was used for viewing videos. This software allowed videos to be played at various speeds and frame-by-frame. The raters were allowed to independently watch the videos as many times as

| Score | 1. Lower Extremity valgus at landing   | 2. Thighs do not reach parallel  | 3. Thighs not equal side-to-side during flight                                     | 4. Foot placement not shoulder width apart   | 5. Foot placement not parallel   | 6. Foot contact timing not equal  | 7. Excessive landing contact noise   | 10. Does not land in same foot print   |
|-------|--|--|--|--|--|---|--|--|
| 0     |   |   |   |   |   |   |   |   |
| 1     |   |   |   |   |   |   |   |   |
| 2     |  |  |  |  |  |  |  |  |

**Figure 3.** Modified version of the Tuck Jump Assessment. If participants failed to meet the item criteria (1-10 items) (table 2) two or more times, then they scored one or two (magnitude of the score). If participants met the criteria, then they scored zero for the respective category.

necessary and at whatever speeds they needed to score each test. Both raters were certified strength and conditioning coaches with over five years of clinical experience each and previous training and experience with scoring the TJA from video replay. The two raters then scored the same videos one week later. Another investigator (AF), who was blind to the identity of the raters, performed the statistical analysis of the data (scores of the 10 items). They were blind to their own scores the week before. Finally, the third investigator, still blind to the identity of the raters, then analyzed the scores from both raters for each participant.

### Data analysis

All data were analyzed using SPSS (version 15.0, SPSS Inc, Chicago, IL) with a priori alpha level of .05. Means and standard deviations of each variable were calculated. The ten items of the modified TJA were analyzed for Kappa coefficient ( $k$ ) and percentage of exact agreement (PEA) [PEA = (agreed/agreed + disagreed)  $\times$  100 for both intra- and inter-rater reliability]. The  $k$  was interpreted based on the scale of Landis and Koch (1977) with 0.01-0.2 being slight, 0.21-0.4 fair, 0.41-0.6 moderate, 0.61-0.8 good and 0.81-1.0 almost perfect (excellent) (Landis and Koch, 1977). Intraclass agreement coefficients (ICCs) from repeated-measures analysis of variance were calculated to determine intra-rater and inter-rater reliability for

the modified TJA total score. In this case, the clinical significance was defined as poor for an ICC below 0.4, fair to good for 0.40–0.75, and excellent for 0.75 or higher (Fleiss, 1986).

## Results

### Inter-rater reliability

The Kappa measure of agreement between the two raters was good to excellent for most items. Only item 9 (“technique declines prior to 10 seconds”) showed a fair correlation between raters (Table 3). Average PEA between the two raters across all scoring criteria for all subjects was 92.1% (range 91.7 – 95.8%). Inter-rater reliability for the total score ( $7.88 \pm 1.98$ ) was excellent (ICC = 0.94, 95% CI = 0.88-0.97).

### Intra-rater reliability

The within session  $k$  for rater 1 across the two viewing sessions was good to excellent for most items. Item 9 (“technique declines prior to 10 seconds”) had a moderate correlation ( $k = 0.51$ ) and item 6 (“foot contact timing not equal”) had no correlation ( $k = 0.00$ ) (Table 4). Rater 2 had a good to excellent correlation across all items. Average percentage exact agreement (PEA) between sessions across all scoring criteria for all subjects was 90.8% (range 83.3 – 100%) for rater 1 and 95.4% (range 91.7

**Table 2. Scoring criteria for each item of the Modified Tuck Jump Assessment.**

| Phase of jump                | Criterion  | View        | None (0)   | Small (1)  | Large (2)  |
|------------------------------|--|-------------|--|--|--|
| Knee and Thigh motion        | 1. Lower Extremity valgus at landing                               | Frontal (F) | No valgus  | Slight Valgus  | Obvious valgus: Both knees touch   |
|                              | 2. Thighs do not reach parallel (peak of jump)                     | Lateral (L) | The knees are higher or at the same level as the hips        | The middle of the knees are at a lower level than the middle of the hips | The whole knees are under the entire hips  |
|                              | 3. Thighs not equal side-to-side during flight                     | F           | Thighs equal side-to-side                                    | Thighs slightly unequal side-to-side                                     | Thighs completely unequal side-to-side (one knee is over the other)                                    |
| Foot Position During Landing | 4. Foot placement not shoulder width apart                         | F           | Foot placement exactly shoulder width apart                  | Foot placement mostly shoulder width apart                               | Both feet fully together and touch at landing  |
|                              | 5. Foot placement not parallel (front to back)                     | L           | Foot (the end of the feet) placement parallel                | Foot placement mostly parallel   | Foot placement obviously unparallel (one foot is over half the distance of the other foot/leg)         |
|                              | 6. Foot contact timing not equal (Asymmetrical landing)            | F           | Foot contact timing equal side-to-side                       | Foot contact timing slightly unequal                                     | Foot contact timing completely unequal   |
|                              | 7. Excessive landing contact noise                                 | F/L         | Subtle noise at landing (landing on the balls of their feet) | Audible noise at landing (heels almost touch the ground at landing)      | Loud and pronounced noise at landing (contact of the entire foot and heel on the ground between jumps) |
| Plyometric Technique         | 8. Pause between jumps   | F/L         | Reactive and reflex jumps                                    | Small pause between jumps  | Large pause between jumps (or double contact between jumps)  |
|                              | 9. Technique declines prior 10 seconds                             | F/L         | No decline in technique.                                     | Technique declines after five seconds                                    | Technique declines before five seconds   |
|                              | 10. Does not land in same foot print (Consistent point of landing) | F/L         | Lands in same footprint                                      | Does not land in same footprint, but inside the shape                    | Lands outside the shape  |

– 100%) for rater 2. Intra-rater reliability for the total score was excellent for both rater 1 (ICC = 0.94, 95% CI = 0.88-0.97) and rater 2 (ICC = 0.96, 95% CI = 0.92-0.98).

## Discussion

The main objectives of this study were to assess the inter- and intra-rater reliability of the tuck jump assessment with a modified scoring system (0-2). Inter-rater and intra-rater reliability was good to excellent for almost all of the individual criteria and PEA between raters and between sessions across all scoring criteria was also excellent. The ICC values for the total score indicated excellent inter- and intra-rater reliability.

The criteria of technique decline in 10 seconds (item 9) demonstrated fair to moderate reliability on two occasions (inter-rater reliability and intra-rater reliability in rater 1) and unequal foot contact timing (item 6) showed no correlation on one occasion (intra-rater reliability of rater 1). Despite this, PEA was excellent in all occasions. The intra-rater reliability of technique decline in 10 seconds showed only two instances when rater's scores did not agree across trials. Similarly, there were only three occasions when the scores of rater 1 did not agree between the first and second assessments.

Despite the high agreement between raters and assessments, the fair to moderate reliability of this criterion could be explained by the low variability of the item. That is to say, most of the participants scored the same value (1

**Table 3. Kappa coefficient for inter-rater reliability for each item of the Modified Tuck Jump Assessment.**

| Phase of jump                | Criterion                                  | Total Scores Across Raters Mean ( $\pm$ SD) | Kappa value |
|------------------------------|--|---|-------------|
| Knee and thigh motion        | 1. Lower extremity valgus at landing       | 1.13 (.90)                                  | .87         |
|                              | 2. Thighs do not reach parallel            | .40 (.50)                                   | .91         |
|                              | 3. Thighs not equal side-to-side           | 1.17 (.43)                                  | .75         |
| Foot Position During Landing | 4. Foot placement not shoulder width apart | .25 (.49)                                   | .77         |
|                              | 5. Foot placement not parallel             | 1.10 (.31)                                  | .78         |
|                              | 6. Foot contact timing not equal           | .06 (.24)                                   | .65         |
|                              | 7. Excessive landing contact noise         | 1.44 (.55)                                  | .76         |
| Plyometric Technique         | 8. Pause between jumps                     | .13 (.34)                                   | 1.00        |
|                              | 9. Technique declines prior to 10 sec      | 1.00 (.29)                                  | .35         |
|                              | 10. Does not land in same footprint        | 1.21 (.46)                                  | .78         |

**Table 4. Kappa coefficient for intra-rater reliability for each item of the Modified Tuck Jump Assessment.**

| Phase of jump                       | Criterion                                  | Kappa value<br>Tester 1 | Kappa value<br>Tester 2 |
|-------------------------------------|--|-------------------------|-------------------------|
| <b>Knee and thigh motion</b>        | 1. Lower extremity valgus at landing       | .75                     | .94                     |
|                                     | 2. Thighs do not reach parallel            | .91                     | .91                     |
|                                     | 3. Thighs not equal side-to-side           | .61                     | .86                     |
| <b>Foot Position During Landing</b> | 4. Foot placement not shoulder width apart | .75                     | .87                     |
|                                     | 5. Foot placement not parallel             | .63                     | .61                     |
|                                     | 6. Foot contact timing not equal           | .00                     | 1.00                    |
| <b>Plyometric Technique</b>         | 7. Excessive landing contact noise         | .75                     | .85                     |
|                                     | 8. Pause between jumps                     | .61                     | 1.00                    |
|                                     | 9. Technique declines prior to 10 sec      | .51                     | .63                     |
|                                     | 10. Does not land in same footprint        | 1.00                    | .88                     |

point). In fact, only one subject scored two points in this item. The low variability of the item could be explained by the homogeneity of the sample as all participants were well-trained elite youth volleyball athletes. Future research should investigate the reliability of the modified TJA scoring criteria in different types of athletes, such as recreational athletes of various ages and growth and maturation levels. A more heterogeneous sample may result in a wider range of TJA scores and an area for further evaluation in comparative studies. With regard unequal foot contact timing the findings were similar to those of technique decline in 10 seconds. Despite the fact that rater 1 lacked agreement for only one subject, the  $k$  value showed the item was not reliable; however, PEA was excellent. Almost all of the study participants scored zero on this item. Again, this finding could be explained by the low variability likely resulting from the homogenous, well-trained sample.

Our findings support previous research, whereby an initial pilot study reported moderate to strong inter-rater reliability (Myer et al., 2008b) of the original TJA. More formal inter- and intra-rater reliability of the TJA demonstrated excellent agreement when scoring 10 recreationally active university students at two different scoring sessions (Herrington et al., 2013). More recently, Read et al. (2016b) investigated the intra-rater reliability for the TJA total score and found that it was strong (ICC = 0.88) in a sample of elite male youth soccer players.

Although the reported reliability of this test is high, existing research has its limitations including a lack of specific information concerning training of raters and the small sample sizes used. Dudley et al. (2013) obtained poor to moderate inter-rater and intra-rater reliability of the TJA with raters of different educational and clinical backgrounds (Dudley et al., 2013). They concluded that the published protocol was not detailed enough and that training of their raters were not sufficient to allow for consistent TJA scoring. A secondary goal of this research was to improve the instructions and specificity of the TJA scoring system in order to improve its validity in both clinical and performance contexts.

In the current study the reliability between two separate TJA sessions was examined. Only one study has reported the within-subject inter-session reliability (two sessions separated by one week) (Read et al., 2016b). In elite male youth soccer players, when each criteria was analyzed individually, Kappa coefficients determined that knee valgus was the only criterion to reach substantial

agreement across the two test sessions for both pre and post peak height velocity players. Future research should establish the test-retest reliability of the TJA with modified scoring. This may allow for the new scoring system to be used to evaluate the effects of neuromuscular training interventions. In addition, future research should compare raters' scores of athletes in real time to raters' retrospective scores of athletes using video playback. If the two methods results in similar scores the real time measurement can be used to save time and provide the athlete with easy, real time progress.

The modified TJA is a user-friendly clinical tool that requires minimal equipment, takes only minutes to administer, and appears to provide a useful update to the initial assessment protocol. In addition, this test assesses a functional task that reflects a high intensity, sport-specific movement associated with fatigue and ACL injury mechanisms in situational sports. Moreover, these results create a basis for future work aimed at establishing the validity of the TJA. Finally, it's important to consider that criterion items in the test are not equal with regard to ACL injury risk. Currently, research has only shown that increased dynamic valgus (item 1) during a drop landing is a risk factor for ACL injury, with a sensitivity and specificity of 78% and 67%, respectively (Hewett et al., 2005). A consideration for further modifications to the TJA scoring criteria include adding weight to items that are known to contribute to ACL injury, including knee valgus (item 1).

## Conclusion

This research demonstrated that the modified version of the tuck jump test shows good to excellent intra- and inter-rater reliability for most items using retrospective video analysis. These findings indicate that the modified version of the TJA could be used to assess repeated jump-landing technique. The TJA may not only be helpful for coaches and clinicians planning neuromuscular programs to improve performance, but it may also be useful for injury prevention to target deficits associated with injury risk. This tool provides a user-friendly option that requires minimal equipment, takes only minutes to administer, and could help to detect both reductions in high-risk movement patterns resulting from neuromuscular training and increases in high-risk movement patterns as a result of fatigue, injury or growth disturbances. In addition, the benefits of neuromuscular deficit assessment may be of

special relevance to athletes whose activity involves jumping, sidestepping, cutting maneuvers, and deceleration tasks, all of which have been related to a high incidence of injury (Waldén et al., 2015).

Future research should focus on establishing the validity of this test. Specifically, more information is needed in order to examine if a higher TJA score is associated with ACL neuromuscular risk factors, but also with incidence of ACL injury.

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### Key points

- The modified TJA shows good to excellent intra- and inter-rater reliability.
- This test is useful for assessing repeated jump-landing technique.
- This test provides a user-friendly option for assessing high-risk movement patterns.

### AUTHOR BIOGRAPHY

#### Azahara FORT- VANMEERHAEGHE

##### Employment

Assoc. Prof. at the School of Health and Sport Sciences (EUSES), University of Girona, Spain and Strength and conditioning coach of elite female youth basketball players (Segle XXI team, Catalan Federation of Basketball).

##### Degree

PhD

**Research interests** Injury prevention, Return to sports, Integrative neuromuscular training, pediatric exercise science

**E-mail:** afortvan@gmail.com

#### Alicia M. MONTALVO

##### Employment

Assistant Professor of Athletic Training at Florida International University, Miami, FL

##### Degree

PhD

##### Research interests

Injury epidemiology; injury prevention; epigenetics; precision medicine

**E-mail:** amontal@fiu.edu

#### Rhodri S. LLOYD

##### Employment

Senior Lecturer in Strength and Conditioning at Cardiff Metropolitan University.

##### Degree

PhD in Paediatric Exercise Science

**Research interests:** paediatric strength and conditioning, long-term athletic development

**E-mail:** rlloyd@cardiffmet.ac.uk

#### Paul J. READ

##### Employment

Research Scientist for the Research Department at Aspetar Sports Medicine Hospital

##### Degree

PhD

**Research interests** paediatric strength and conditioning, long-term athletic development

**E-mail:** paul.read@stmarys.ac.uk

#### Gregory D. MYER

##### Employment

Director of Research and the Human Performance Laboratory for the Division of Sports Medicine at Cincinnati Children's Hospital Medical Center

##### Degree

PhD

**Research interests** Injury biomechanics; human performance; pediatric exercise science; preventative medicine; sensorimotor neuroscience.

**E-mail:** greg.myer@cchmc.org

#### ✉ Azahara Fort-Vanmeerhaeghe

School of Health and Sport Sciences (EUSES) Universitat de Girona, Salt, Spain