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Single-Leg Countermovement Jump Compensation Assessment: Content Validity of a Checklist

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ABSTRACT

Jump actions are common in several sports, and their performance is related to a myriad of biomechanical and physiological factors, with links to athletic performance and imbalances. Currently, a valid, field-based, easy-to-use tool to assess the quality of an explosive jump movement, similar to the required sports movements, is unavailable. Thus, the present study aimed to design and validate a field-based, easy-to-use tool that can be used to assess the quality of movement during an explosive single-leg countermovement jump (SL-CMJ). Ten experts participated in the content validation process for the checklist, including checking item relevance, definition accuracy, and scoring adequacy. Content validity was measured using the Aikens V format. The checklist included the items "Foot orientation," "Knee valgus/varus," "Internal/external hip flexed orientation," "Pelvis tilt," "Thorax tilt," "Thorax rotation," "Foot pronation/supination," "Asymmetrical hip," and "Lumbopelvic association". The items achieved a 0.60–0.99 in relevance, 0.70–1.00 in definition accuracy, and 0.80–0.83 in scoring adequacies in the Aikens V proof. The results from the context validation process suggest that the tool may be appropriate to assess athletes' quality of explosive movement. Furthermore, the results derived from such assessments may help to design better and safer training interventions.

Introduction

Muscular strength and power are key factors in human health and performance [1]. Many studies elucidate how different training methodologies enhance human performance and health, and correlate with parameters such as rate of falls, gait ability, balance, etc. [2]. In addition, training reduced the risk of suffering injuries, especially common and serious ones like the anterior cruciate ligament (ACL) [3]. Both strength and neuromuscular imbalances are directly related to injury risk factors [4, 5]. The movement quality is characterized by capacity to execute motions in a precise and efficient manner [6]. Thus, the neuromuscular imbalances are usually labelled as an important part of human quality of movement, defined as the movement executed with proper posture, breathing, mobility and coordination in activities or specific tasks performed optimally and efficiently [7]. This is related to process-oriented measures, which focus on the execution of movement [8]. Current literature provides different tests to measure the quality of movement [7, 9]. Despite this test battery being helpful to the coaches and strength professionals, none of these tests includes the quality of movement during a force or power task. This quality of movement measure seems to disappear when power and strength are measured. However, daily life activities and the majority of sports tasks require fast and robust movements, and we need to ensure that would be achieved in the proper form [10]. To ensure this quality of movement and detect neuromuscular imbalances, the identification of compensations during movement is essential for preventing, mitigating and treating movement impairments. Related to that, compensation is defined as "an alteration in movement strategy in relation to a baseline (e. g. previous state or a control group). Compensation in movement strategies originates from the redundancy in the muscle architecture of the human body. Humans compensate by altering their movement trajectory and/or altering the muscle recruitment to complete a task" [11].

Nowadays, literature shows tools to ensure and quantify specific movements, but the results are too tedious, costly and complicated to be used in practical and real situations [12, 13]. In addition, current technology and scientific advances allow sports professionals and coaches to ensure a good performance measure in real situations, with a proper reliability, and without cost [14]. However, to the authors' knowledge, no instrument exists that could measure power and strength and, with the same test, ensure a good movement quality. Countermovement jump (CMJ) is widely used to evaluate lower limb muscle strength and power [15]. As mentioned above, these parameters can be measured quickly with a mobile application and at almost no cost, with good inter and intra-observer reliability [14]. However, the literature has not shown available tools to accurately assess these parameters to ensure a good quality of movement in the same test. Nevertheless, single-leg countermovement jump (SL-CMJ) seems to be a more accurate measure of strength, power and asymmetries than CMJ, although this one is not so popular [16]. The characteristic of this unilateral test could help coaches better assess athletes to compare asymmetries between limbs, not only strength imbalances but neuromuscular imbalances, too. For this reason, this exercise was selected to test the validity of an expert checklist to ensure a good quality of movement when strength and power come into play.

How poor technique and quality of movement are also related to injuries [17]; coaches could use this tool to determine the degree of risk of injury and neuromuscular imbalances for each athlete. In this manner, they could determine which area is more prone to injury and focus efforts on addressing it. In addition, this instrument could help standardize this exercise technique and be used more appropriately in future research studies. Due to these reasons, the authors believe that if this tool becomes validated it could contribute to a significant advance in the scientific and practiced areas for coaches and academics. Thus, since i) strength and conditioning coaches need a tool to assess motor skills, ii) quantitative measuring is needed to standardized athletes and people's abilities, and iii) no specific test measured the quality of execution on SL-CMJ that seems to be more accurate to evaluate lower limb muscle strength and power, the present study aimed to design and validate an easy, simple and concise protocol that can be measured in a field-based context to provide sport science experts with information about the quality of movement in the single-leg countermovement jump.

Materials and Methods

Design

This study was designed to examine the validity of a new protocol to assess SL-CMJ. To assess the quality of movement and evaluate the technique of this exercise, the list of compensatory movements that humans can produce, as described by Hernandez-García et al. (2020) was followed. Considering the scientific literature [7, 11, 18] and the authors' criteria, a list of potentially relevant SL-CMJ compensations was elaborated. The SL-CMJ compensation assessment considered three points of view: frontal (foot orientation, knee orientation, hip flexed orientation, pelvis tilt, pelvic rotation, thorax tilt, thorax rotation), posterior (foot pronation/supination, pelvis tilt asymmetry), and lateral (hell lift, lumbopelvic association, thoracic curvature). Therefore, the initial question posed to the experts pertained to the relevance of each proposed compensation. After that, with each author's consensus, a definition of each compensation was elaborated (▶ **Table 1**). Once all of these variables were defined, a score was given to each item and a document was created that contained three sections per variable analyzed; item relevance, definition accuracy (where the description of the compensation was reported) and scoring adequacy (where asked about the appropriate score). Experts used a Likert-type quantitative scale to evaluate each section from 1 to 10, and an extra column was also provided in case any observation/suggestion was required [19].

Expert panel

Similar to previous studies, and in order to ensure a statistically significant power, a total of 10 experts were gathered [7]. The experts need to accomplish the following inclusion criteria: a) be a PhD in Sports Sciences; b) have more than two years of experience in functional assessment in both athletes and non-athletic populations; c) be active in the professional training/physiotherapy world at present. The expert panel checklist was sent to experts to respond in

▶ **Table 1** Definition and items proposed by authors based on the scientific literature and their criteria.

Frontal view	
Foot orientation	The supported foot tiptoe is oriented outwards/inwards in relation to the supported shinbone.
Knee rotation	The jump leg knee is oriented inwards, close to the vertical body axis, or outwards, increasing the distance to the vertical body axis.
Hip flexed orientation	Not jumped leg hip orientation outwards/inwards, leaving the leg in bending orientation out of the medial line of the body.
Pelvis tilt	Some of two pelvises drop right/left to the vertical body axis.
Pelvic rotation	Some of two pelvises rotate, staying one forward than the other.
Thorax tilt	Some of two trunk sides fall down relative to the vertical body axis.
Thorax rotation	Trunk rotation outwards/inwards in relation to the vertical body axis.
Posterior view	
Foot pronation/supination	Plantar arch very pronounced or felled in the jump foot.
Pelvis tilt asymmetry	Displacement of the pelvis in the posterior view towards the jumped/not jumped leg.
Lateral view	
Hells lift	Lift the heel-foot during the eccentric phase.
Lumbopelvic association	Lumbar neutral curvature disappears or increases too much.
Thoracic curvature	The convexity of the dorsal curvature disappears or increases too much.

a fortnight. Using the information gathered during the first review, if an item receives a rating below 5 from three or more experts (it is understood that there is significant variation and potential confusion), or obtained Aiken's V coefficient < 0.6, the item was removed. After that, a new report was written with the obtained feedback, and the same group of qualified experts was asked to review and answer again with the same methodology. After the second data collection, the list of variables with definitions and measures was closed.

Statistical analysis

First, to calculate the sample size (experts) required to reach a significant statistical power the next equation was used [20]:

$$n \sim \left(\frac{Z_{1-\frac{\alpha}{2}} + Z_{1-\beta}}{d}\right)^2 * 2 \quad (1)$$

n = required sample size, α = significance level; *d* = effect size; β = the probability of failure to reject a false null hypothesis; Z = value in the standard normal distribution

The selected effect size is 0.8, as recommended in the literature [20], with a significance level of 0.05 and a statistical power of 0.95.

The data were registered, and a descriptive analysis was performed (mean, median and mode). The content validity was calculated using Aiken's V, using the following equation [21]:

$$V = \frac{\overline{X} - l}{k} \quad (2)$$

V = Aiken's V coefficient; $\overline{X}$ = average of the judges' scores; l = Minimum rating; k = the subtraction of the maximum grade minus the minimum grade.

The statistic V provides an index of rater endorsement that ranges from 0 (all judges select the lowest possible rating) to 1 (all judges select the highest possible rating). The inferential procedure for Testing hypotheses related to Aiken's V has several drawbacks. These drawbacks of the hypothesis test can be overcome using a confidence interval for V [22]. The equations used to extract the confidence intervals are:

$$U = \frac{2nkV + Z^2 + Z\sqrt{4nkV(1-V) + Z^2}}{2(nk + Z^2)} \quad (3)$$

L = lower limit of the confidence interval; U = upper limit of the confidence interval; Z = value in the standard normal distribution according to confidence level (for 95 % confidence Z = 1.96, for 99 % confidence Z = 2.58); V = Aiken's V coefficient; k = is the subtraction of the maximum rating minus the minimum rating; n = number of judges.

Results

Sample Size

The sample size calculation to calculate the number of experts required was 8.64, thus, with the opinion of 9 experts we achieved a statistical power greater than 0.95. However, to ensure the statistical quality, 10 experts were used.

First Review

From the 12 items analyzed that contained the first draft of the SL-CMJ checklist, three were removed due to experts considering items relevance was poor (Aiken's V coefficient < 0.6). Thus, "pelvis rotation" (V = 0.41), "Hell lift" (V = 0.58) and "Thoracic curvature" (V = 0.49) were deleted. Therefore, the nine items finally included in the SL-CMJ were: "Foot orientation" (V = 0.97), "Knee Valgus/Varus" (V = 0.99), "Internal/External Hip flexed orientation" (V = 0.69), "Pelvis tilt" (V = 0.60), "Thorax tilt" (V = 0.78), "Thorax rotation" (V = 0.88), "Foot Pronation/Supination" (V = 0.64), "Asymmetrical hip" (V = 0.79) and "Lumbo-pelvic association" (V = 0.76) (▶ **Table 2**).

The accuracy of the definitions was optimal for all items (0.64, 0.97, 0.87, 0.88, 0.60, 0.72, 0.69, 0.63, and 0.84 points of Aikens'

▶ **Table 2** Item relevance of the first 12 items.

Item relevance	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Item 12
Aikens V Penfield and Giocobi	0.97	0.99	0.69	0.60	0.41	0.78	0.88	0.64	0.79	0.58	0.76	0.49
Lower limit IC 95 %	0.91	0.94	0.59	0.50	0.32	0.68	0.79	0.54	0.69	0.47	0.66	0.39
Upper limit IC 95 %	0.99	1.00	0.78	0.70	0.51	0.85	0.93	0.74	0.86	0.67	0.83	0.59

▶ **Table 3** Definition accuracy of the items included.

Definition accuracy	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9
Aikens V Penfield and Giocobi	0.90	1.00	0.93	0.83	0.70	0.93	0.79	0.84	0.98
Lower limit IC 95 %	0.82	0.96	0.86	0.74	0.60	0.86	0.69	0.76	0.92
Upper limit IC 95 %	0.95	1.00	0.97	0.90	0.78	0.97	0.86	0.91	0.99

▶ **Table 4** Scoring adequacy of the items included.

Scoring adequacy	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9
Aikens V Penfield and Giocobi	0.81	0.80	0.83	0.83	0.82	0.80	0.82	0.82	0.81
Lower limit IC 95 %	0.72	0.71	0.74	0.74	0.73	0.71	0.73	0.73	0.72
Upper limit IC 95 %	0.88	0.87	0.90	0.90	0.89	0.87	0.89	0.89	0.88

V respectively). However, some definitions were slightly modified, based on experts' recommendations, in an attempt to improve results in the second review.

The overall scoring adequacy was slightly poor, with 0.53 ± 0.03 in Aikens V (0.52, 0.54, 0.52, 0.58, 0.51, 0.54, 0.53, 0.58, and 0.51 points of Aikens' V respectively of each item). Consequently, a 0 or 1-point scale for each compensation was modified by a 3-point scale of 2 (perfect performance), 1 (minor compensation), and 0 (major compensation/inability to perform).

Second review and final checklist version

For the second round, the SL-CMJ checklist was modified according to the expert feedback and was consulted again about the definition accuracy and scoring adequacy. The accuracy of the definitions was optimal for all items (0.90, 1.00, 0.93, 0.83, 0.70, 0.93, 0.79, 0.84, and 0.98 points of Aikens' V respectively) (▶ **Table 3**).

The scoring adequacy was optimal for all items (0.81, 0.80, 0.83, 0.83, 0.82, 0.80, 0.82, 0.82, and 0.81 points of Aikens' V respectively) (▶ **Table 4**).

The ▶ **Table 5** includes the final version of the SL-CMJ assessment checklist (▶ **Table 5**).

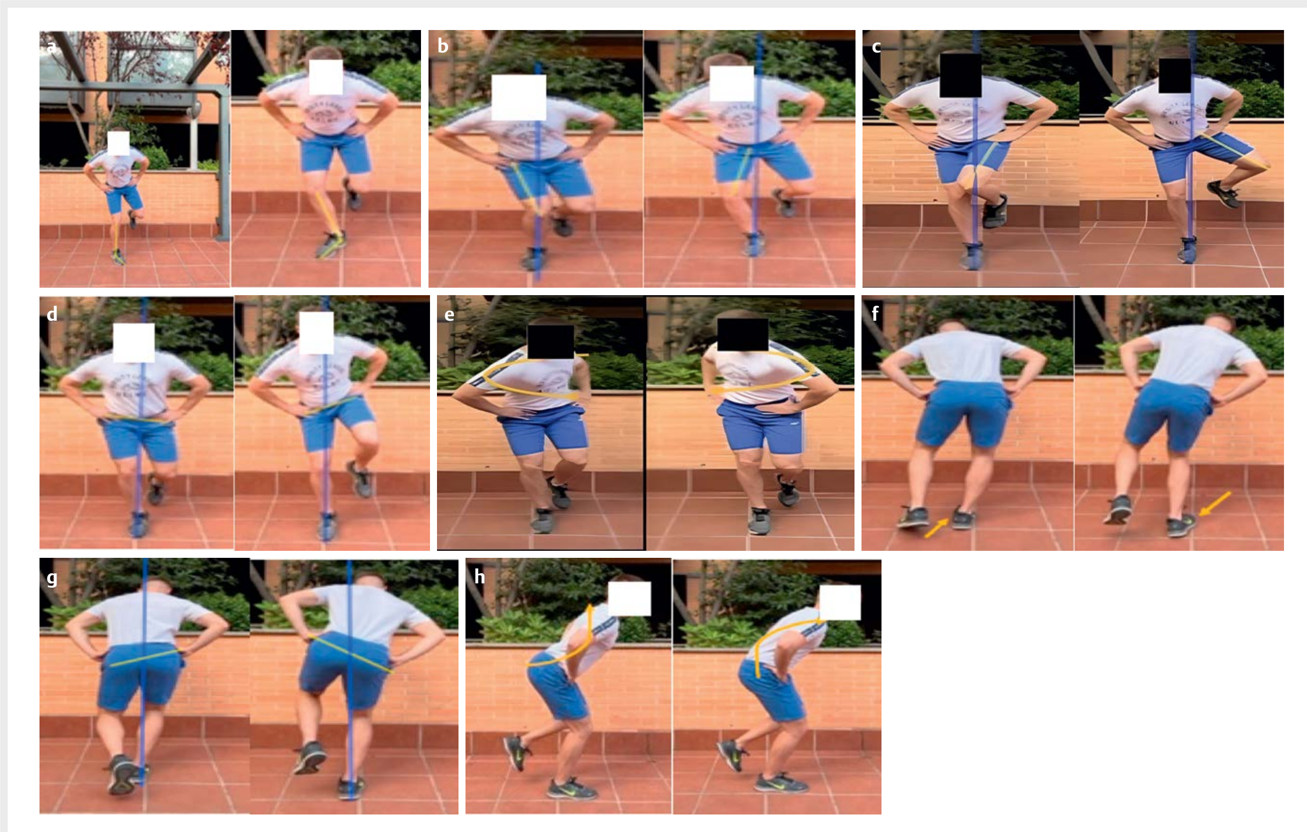
Discussion

This study aimed to design and validate an easy, simple and concise protocol that can be measured in a field-based context to provide sport science experts with information about the quality of movement in the single-leg countermovement jump. In the expert opinions, the SL-CMJ assessment checklist was a relevant, accurate and adequate tool. The final version of this tool included *foot orientation, knee valgus/varus, internal/external hip flexed orientation, pelvis tilt, thorax rotation, foot pronation/supination, asymmetrical hip and lumbopelvic association* items.

From the frontal view, the first five items could be assessed. Foot orientation has a strong relationship with balance and ankle stabilizers [23]; perhaps this would be the reason that high levels of satisfaction were reached among experts, which could represent valuable information for athletes preventing injuries and improving performance in some sports and activities that require good balance and ankle stability (e. g. skiing, snowboarding, basketball, etc.) [23]. The knee valgus/varus was reported with the highest relevance and definition accuracy for all those included. Increased knee valgus is one of the reasons that may contribute to increased ACL risk injury [24] and this injury is one of the biggest concerns by sports professionals due to its prevalence. These two first items (foot orientation and knee valgus/varus) were the most relevant for experts and the most concerning causes for strength and conditioning coaches. Thus, according to these results, for the second and final version of this checklist, which showed not high scores in the scoring adequacy on the first round, the authors decided to give it greater importance, giving it 2 or 3 points instead of 1 or 2, if some type of compensation was observed. This modification resulted in improved scoring adequacy for all items included. Despite the good results obtained, a 3-level scale may be more difficult for coaches to use in practice situations to determine whether a major or minor compensation was executed. Thus, to determine whether compensation is major or minor, strength and conditioning professionals can consider the following key factors: the magnitude of compensation, the duration of compensation and the impact of the compensation on performance or health for their sport or practice. The magnitude of compensation could be determined by the peak of flagrant fault. For example, an athlete could perform 10 degrees of knee valgus, which could be determined a minor compensation, and 20 degrees could be a major compensation. The duration of the compensation could be determined whether compensation is minor or major. For example, a knee valgus only during the propulsive phase could be a minor compensation and knee valgus

▶ **Table 5** Single-Leg Countermovement Jump (SL-CMJ) assessment checklist.

Frontal view			
Foot orientation **Definition:** The supported foot is oriented outwards so that the femur is externally rotated and the knee of the landing leg can align over the toe of the landing foot. **Scoring:** 3 points if major compensation is observed. 2 points if minor compensation is observed. 0 points if compensation is not observed	See ▶ **Fig 1a**		
Knee valgus/varus **Definition:** The jump leg knee is oriented inwards, close to the vertical body axis, or outwards, increasing the distance to the vertical body axis. **Scoring:** 3 points if major compensation is observed. 2 points if minor compensation is observed. 0 points if compensation is not observed.	See ▶ **Fig 1b**		
Internal/external hip flexed orientation **Definition:** Non-jump leg hip oriented outwards/inwards, leaving the leg in a bending orientation outside the medial line of the body. **Scoring:** 2 points if major compensation is observed. 1 point if minor compensation is observed. 0 points if compensation is not observed.	See ▶ **Fig 1c**		
Pelvis tilt **Definition:** Some of the two pelvises drop right/left to the vertical body axis. **Scoring:** 2 points if major compensation is observed. 1 point if minor compensation is observed. 0 points if compensation is not observed.	See ▶ **Fig 1d**		
Thorax rotation **Definition:** Some of two trunk sides fall down relative to the vertical body axis. **Scoring:** 2 points if major compensation is observed. 1 point if minor compensation is observed. 0 points if compensation is not observed.	See ▶ **Fig 1e**		
Posterior view			
Foot pronation/supination **Definition:** Plantar arch very pronounced or felled in the jump foot. **Scoring:** 2 points if major compensation is observed. 1 point if minor compensation is observed. 0 points if compensation is not observed.	See ▶ **Fig 1f**		
Asymmetrical hip **Definition:** Displacement of the pelvis in the posterior view towards the jumped/not jumped leg. **Scoring:** 2 points if major compensation is observed. 1 point if minor compensation is observed. 0 points if compensation is not observed.	See ▶ **Fig 1g**		
Lateral view			
Lumbo-pelvic association **Definition:** Lumbar neutral curvature disappears or increases too much. **Scoring:** 2 points if major compensation is observed. 1 point if minor compensation is observed. 0 points if compensation is not observed.	See ▶ **Fig 1h**		
Overall Score			
21 points → 0	16 points → 2	10 points → 5	4 points → 8
20 points → 0	15 points → 2.5	9 points → 5.5	3 points → 8.5
20 points → 0	14 points → 3	8 points → 6	2 points → 9
19 points → 0.5	13 points → 3.5	7 points → 6.5	1 point → 9.5
18 points → 1	12 points → 4	6 points → 7	0 points → 10
17 points → 1.5	11 points → 4.5	5 points → 7.5	



▶ **Fig. 1** **a:** Foot orientation. **b:** Knee valgus/varus. **c:** Internal/external hip flexed orientation. **d:** Pelvis tilt. **e:** Thorax rotation. **f:** Foot pronation/supination. **g:** Asymmetrical hip. **h:** Lumbo-pelvic association.

during propulsive and landing could be a major compensation. Finally, the impact of the compensation on performance can help to determine whether a minor or major compensation was performed. For example, snowboarding requires a specific ankle position that is not necessary for other activities [25].

The internal/external hip flexed item could be relevant and interesting due to the relationship with ACL injury risk, considering that optimization of SL-CMJ to reduce injury risk can be facilitated by reduced hip adduction angle and increased knee adduction angle [26]. The pelvic tilt obtained 0.60 item relevance, 0.83 definition accuracy, and 0.83 scoring adequacy; however, this item could be controversial due to the differences between sexes in pelvis physiology [27]. Thus, strategies for maintaining pelvis alignment were gender-specific. Finally, thorax rotation is related to ACL injuries and thorax posture could determine activation in the lower limb during the task [28]. Coaches that found this compensation on their athletes should focus on core training, which is related to dynamic balance and ACL injuries [24, 29], in order to address deficiencies in core muscle activation (e. g. pelvis tilt is related to poor gluteus activation) [30].

From the posterior view, the foot pronation/supination and asymmetrical hip were assessed. Ankle kinematics and postural stability affect significantly single-leg landings and could be determinants to ensure good quality movements for athletes [31]. Functional deficits and ankle instability are related to ankle injuries and knee injuries [32]. In addition, core training is related to dynamic balance stability and could help with hip stabilization [29]. Thus, these two items seem to be relevant and could provide interesting information to coaches and could help to provide information to program the training.

From a lateral view, lumbo-pelvic association is related to both overuse and acute injuries and could be determinant in different types of sports [17, 33]. In conclusion, injury prevention and assessment of the quality of movement are among the main concerns of strength and conditioning professionals. For example, a new study showed how biomechanics patterns are associated with ACL injuries in basketball professional players [34]. For this reason, it is important to include this type of field-based tool to help strength and conditioning coaches detect movement quality and future injury risks.

Limitations

Despite the higher benefits provided by this study, this was the first use of the SL-CMJ tool. In spite of undergoing a statistical review and being deemed relevant, accurate, and adequate by experts, further research with various statistical analyses, including Cohen's Kappa analysis, is necessary to ensure the reliability of this tool. Therefore, future studies could involve strength and conditioning coaches using this tool with different samples to evaluate both inter- and intra-observer reliability. Although we included free text responses, which allowed us to gain deeper insight into each expert's opinion about this tool, it was not possible to satisfy all opinions, as some of them were contradictory. Despite the expert panel being of a high-quality level in the area, there is a possibility that some strength and conditioning professionals did not reach a consensus with this tool.

Conclusions and Practical Applications

These results provide strength and conditioning coaches with a valid tool to assess the quality of movement during SL-CMJ. This field-forward tool is designed for use in real-world, practical settings rather than in a controlled laboratory environment. As a result, it is easy, simple and concise. In addition, due to increased awareness among strength and conditioning coaches and trainers about treatment and injury prevention, this checklist could help in this area. The SL-CMJ assessment tool could identify athletes with poor movement quality so that appropriate training interventions can be implemented to reduce their risk of injury. In addition, it could be used to design individualized training programs for athletes based on their specific needs. For example, an athlete with poor foot orientation during the SL-CMJ could be given exercises to improve their foot stability. It is also helpful to track athletes' progress over time. This could be helpful for evaluating the effectiveness of training interventions and for identifying athletes who may need additional support. In contrast to other methods, such as motion capture analysis, the SL-CMJ is faster to use and administer, and it is portable and can be completed in less than a minute. Overall, it is the first scientific validity tool that quantitatively measures the qualitative quality of movement in powerful and fast movement.

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Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Caspersen CJ, Powell KE, Christenson GM. Physical Activity, Exercise, and Physical Fitness: Definitions and Distinctions for Health-Related Research. Public Health Rep 1985; 100: 126–131

[2] Cadore EL, Rodríguez-Mañas L, Sinclair A et al. Effects of Different Exercise Interventions on Risk of Falls, Gait Ability, and Balance in Physically Frail Older Adults: A Systematic Review. Rejuvenation Res 2013; 16: 105–114

[3] Carrasco-Huenulef C, Poblete-Garrido M, Monrroy-Uarac M et al. Effects of a neuromuscular training program on anterior cruciate ligament injury risk factors in youth female basketball players: A pilot study. Gazz Med Ital – Arch Sci Med 2019; 178: 137–144

[4] Hewett TE, Ford KR, Hoogenboom BJ et al. Understanding and preventing ACL injuries: Current biomechanical and epidemiologic considerations-update 2010. N Am J Sports Phys Ther 2010; 5: 234–251

[5] Jeong J, Choi D-H, Shin CS. Core Strength Training Can Alter Neuromuscular and Biomechanical Risk Factors for Anterior Cruciate Ligament Injury. Am J Sports Med 2021; 49: 183–192

[6] Venek V, Kranzinger S, Schwameder H et al. Human movement quality assessment using sensor technologies in recreational and professional sports: A scoping review. Sensors (Basel) 2022; 22: 4786

[7] Hernández-García R, Gil-López MI, Martínez-Pozo D et al. Validity and Reliability of the New Basic Functional Assessment Protocol (BFA). IJERPH 2020; 17: 4845

[8] Goodway JD, Ozmun JC, Gallahue DL. Understanding motor development: Infants, children, adolescents, adults. Singapore: Jones & Bartlett Learning; 2019

[9] Teyhen DS, Shaffer SW, Lorenson CL et al. The functional movement screen: A reliability study. JOSPT 2012; 42: 530–540

[10] Foram B. High-Performance Sports Conditioning. Illinois, USA: Human Kinetics; 2000

[11] van der Kruk E, Silverman AK, Koizia L et al. Age-related compensation: Neuromusculoskeletal capacity, reserve & movement objectives. J Biomech 2021; 122: 110385

[12] Chambers R, Gabbett TJ, Cole MH et al. The Use of Wearable Microsensors to Quantify Sport-Specific Movements. Sports Med 2015; 45: 1065–1081

[13] Nascimento N, Sideris V, Read PJ. Biomechanical Analysis of the Tuck Jump Assessment. J Strength Cond Res 2022; 36: 2946–2949

[14] Gallardo-Fuentes F, Gallardo-Fuentes J, Ramírez-Campillo R et al. Intersession and Intrasession Reliability and Validity of the My Jump App for Measuring Different Jump Actions in Trained Male and Female Athletes. J Strength Cond Res 2016; 30: 2049–2056

[15] Petrigna L, Karsten B, Marcolin G et al. A Review of Countermovement and Squat Jump Testing Methods in the Context of Public Health Examination in Adolescence: Reliability and Feasibility of Current Testing Procedures. Front Physiol 2019; 10: 1384

[16] Cohen WD, Burton A, Wells C et al. Single vs Double Leg Countermovement Jump Tests. Aspetar Sports Med J 2020; 34–41

[17] Dudagoitia E, García-de-Alcaraz A, Andersen LL. Safety of powerlifting: A literature review. Sci Sports 2021; 36: e59–e68

[18] Bonazza NA, Smuin D, Onks CA, Silvis ML, Dhawan A. Reliability, Validity, and Injury Predictive Value of the Functional Movement Screen: A Systematic Review and Meta-analysis. Am J Sports Med 2017; 45: 725–732

[19] Croasmun JT, Ostrom L. Using likert-type scales in the social sciences. J Adult educ 2011; 40: 19–22

[20] Zhang X, Hartmann P. How to calculate sample size in animal and human studies. Front Med 2023; 10: 1215927. DOI: 10.3389/fmed.2023.1215927

[21] Aiken LR. Three coefficients for analyzing the reliability and validity of ratings. Educ Psychol Meas 1985; 45: 131–142

[22] Penfield RD, Giacobbi PR Jr. Applying a Score Confidence Interval to Aiken's Item Content-Relevance Index. Meas Phys Educ Exerc Sci 2004; 8: 213–225

[23] De Ridder R, Willems T, De Mits S et al. Foot orientation affects muscle activation levels of ankle stabilizers in a single-legged balance board protocol. Hum Mov Sci 2014; 33: 419–431

[24] Larwa J, Stoy C, Chafetz RS et al. Stiff landings, core stability, and dynamic knee valgus: A systematic review on documented anterior cruciate ligament ruptures in male and female athletes. Int J Environ Res Public Health 2021; 18: 3826

[25] Delorme S, Tavoularis S, Lamontagne M. Kinematics of the ankle joint complex in snowboarding. J Appl Biomech 2005; 21: 394–403

[26] Gupta D, Reinbolt JA, Donnelly CJ. Optimizing whole-body kinematics during single-leg jump landing to reduce peak abduction/adduction and internal rotation knee moments: Implications for anterior cruciate ligament injury risk. J Appl Biomech 2021; 37: 432–439

[27] Weltin E, Gollhofer A, Mornieux G. Effect of gender on trunk and pelvis control during lateral movements with perturbed landing. Eur J Sport Sci 2016; 16: 182–189

[28] Smeets A, Vanrenterghem J, Staes F et al. Are ACL reconstructed athletes more vulnerable to fatigue than uninjured athletes? Med Sci Sports Exerc 2020; 52: 345–353

[29] Barrio ED, Ramirez-Campillo R, Garcia de Alcaraz Serrano A et al. Effects of core training on dynamic balance stability: A systematic review and meta-analysis. J Sports Sci 2022; 40: 1815–1823

[30] Semciw A, Neate R, Pizzari T. Running related gluteus medius function in health and injury: A systematic review with meta-analysis. J Electromyogr Kinesiol 2016; 30: 98–110

[31] Kunugi S, Koumura T, Myotsuzono R et al. Directions of single-leg landing affect multi-segment foot kinematics and dynamic postural stability in male collegiate soccer athletes. Gait Posture 2020; 80: 285–291

[32] Hwang K-T, Sung I-H, Choi J-H et al. A higher association of medial collateral ligament injury of the knee in pronation injuries of the ankle. Arch Orthop Trauma Surg 2018; 138: 771–776

[33] Nicola TL, Jewison DJ. The anatomy and biomechanics of running. Clin Sports Med 2012; 31: 187–201

[34] Gill VS, Tummala SV, Boddu SP et al. Biomechanics and situational patterns associated with anterior cruciate ligament injuries in the National Basketball Association (NBA). Br J Sports Med 2023; 57: 1395–1399. DOI: 10.1136/bjsports-2023-107075

