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Are the five consecutive vertical jumps a reliable evaluation tool in Olympic and Paralympic sprinters? A cross-sectional study

Thiago Fernando Lourenço [a*] | **Rubens Venditti Júnior [b]** | **Osvaldo Tadeu Júnior [b]** | **Amaury Veríssimo [a]** | **João Paulo Casteleti de Souza [a]** | **Ciro Winckler Filho [a, c]**

a. Brazilian Paralympic Committee, São Paulo, Brazil
b. São Paulo State University Júlio de Mesquita Filho (UNESP), Faculty of Sciences, São Paulo, Brazil
c. Federal University of São Paulo, Santos, Brazil

***Corresponding author(s):** Thiago Fernando Lourenço (PhD), Brazilian Paralympic Committee, São Paulo, Brazil.

Email: thiago.lourenco@cpb.org.br

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Abstract

This study aimed to verify the validity and reproducibility of five vertical jump test (5VJT) as a more specific vertical jump height evaluation tool in elite Olympic and Paralympic sprinters. The present research was a cross-sectional study. For this, 49 sprinters participated, being eighteen with visual impairment, ten with cerebral palsy, seven leg amputees, six arm amputees, and eight non-disabled athletes. The athletes performed squat jump (SJ), countermovement jump (CMJ) and 5VJT. To compare jump height, analysis of variance (ANOVA) was used, intraclass correlation test (ICC) to evaluate the reliability, Bland and Altman to verify agreement of each pair of methods used (CMJ vs 5VJT, SJ vs 5VJT) and Pearson correlation to ascertain the level of association (CMJ vs 5VJT, SJ vs 5VJT) and between the subgroups. The level of significance set for the study was $P<0.05$. Excellent reliability for each method (CMJ-ICC=0.96, 95% confidence interval [CI]:0.96-0.97; SJ-ICC=0.89, 95%CI:0.87-0.90; and 5VJT=ICC=0.98, 95%CI:0.97-0.98) was found and strong to very strong association between them were found in visual impairment athletes-5VJT with CMJ (r=0.85), SJ (r=0.93), leg amputees–5VJT with CMJ (r=0.84), SJ (r=0.92), arm amputees–5VJT with CMJ (r=0.90), SJ (r=0.93), cerebral palsy-5VJT with CMJ (r=0.90), SJ (r=0.95) and AB–5VJT with CMJ (r=0.80), SJ (r =0.92). The reproducibility of ground contact time (GCT) showed good reliability for visual impairment (ICC=0.68, CV=9.5%), leg amputee (ICC=0.72; CV=13.8%) and cerebral palsy (CCI=0.77; CV=14.8%). These data suggest that 5VJT can be reliably applied to measure jump height and GCT, providing practical information about two important variables to monitor muscle fatigue (i.e., jump height and contact time).

Keywords: Vertical Jump, Paralympic, Athletes, Sprinters, Sports, Exercise.

Highlights

- Excellent reliability for each method (CMJ-ICC=0.96, 95%CI:0.96-0.97; SJ-ICC=0.89, 95%CI:0.87-0.90; and 5VJT=ICC=0.98, 95%CI:0.97-0.98) was found and strong to very strong association between them were found in visual impairment athletes-5VJT with CMJ (r=0.85), SJ (r=0.93), leg amputees–5VJT with CMJ (r=0.84), SJ (r=0.92), arm amputees–5VJT with CMJ (r=0.90), SJ (r=0.93), cerebral palsy-5VJT with CMJ (r=0.90), SJ (r=0.95) and AB–5VJT with CMJ (r=0.80), SJ (r =0.92).
- The reproducibility of GCT showed good reliability for visual impairment (ICC=0.68, CV=9.5%), leg amputee (ICC=0.72; CV=13.8%) and cerebral palsy (CCI=0.77; CV=14.8%).
- These data suggest that 5VJT can be reliably applied to measure jump height and GCT, providing practical information about two important variables to monitor muscle fatigue (i.e., jump height and contact time).

1 │ Introduction

Generating power is essential for many sports [1], and assessing lower limb muscle power is crucial for high-performance athletes. Protocols that measure vertical jump height to estimate muscular power have been proposed as tools for identifying fatigue, neuromuscular performance, and training load control [2-4].

The validity and reproducibility of these protocols are fundamental to ensure reliability and practical utility [5]. A force plate is the most precise and accurate method for producing force and power during vertical jump. However, due to its high cost, it is less accessible than the contact mat, which measures flight time and estimates jump height indirectly [6]. Previous studies have found the contact mat more reliable than the force plate in detecting jump height, particularly for heights below 0.70 meters [6-8].

Among the popular assessment protocols for evaluating vertical jump using this method are the countermovement jump (CMJ) and squat jump (SJ) [9]. Numerous studies [7-9] have demonstrated their importance in training load control as sensitive tools for evaluating fatigue levels with high reliability [7-9]. However, these protocols measure these components in a single movement, which may not fully capture the demands of some sports.

Sprinters, for instance, need to generate high rates of strength and power throughout the entire race. They must direct the resultant force vector horizontally during acceleration (i.e. acceleration phase) and vertically during the transition from lower to higher running speeds. During maintenance, sprinters strive to sustain top speed for as long as possible with a shorter ground contact time (GCT) [10]. Maintaining a short GCT (i.e. ~100 ms) throughout the race is crucial for reaching and sustaining maximum speed in top sprinters [11, 12].

However, elite sprinters undergo numerous high-intensity training sessions, which can lead to fatigue and increase the occurrence of exercise-induced muscle damage [13]. This may be associated with changes in neuromuscular control [14], such as decreases in strength, reduced dynamic joint stability [15] and an increased GCT [16]. According to Hazzaa et al., (2023) [17], the skeletal muscle's ability to absorb impact forces decreases when fatigued, increasing the risk of running-related injuries. This may be more pronounced in Paralympic athletes due to increased passive mechanical stiffness in athletes with cerebral palsy, the inability to use ground reaction force effectively on the prosthesis for leg amputees, and challenges in spatial learning for athletes with visual impairments.

Therefore, a training load assessment that includes jump height and GCT would benefit sports scientists and coaches. The drop jump test is a commonly used protocol to measure these variables [18]. Despite the force plate being the gold standard for recording GCT, a contact mat is more accessible for sports clubs and provides reliable assessments [19]. However, this protocol has a limitation in that jump height and GCT are measured in a single jump and depend on the drop height used [20].

In the early 2000s, as an alternative to meeting the demands of team sports and introducing a more complex motor pattern, some studies proposed quantifying the total distance achieved in a series of five horizontal jumps [21-23]. Conversely, although this method is more specific for sprinters, these studies did not measure GCT.

No study has investigated the validity and reproducibility of the consecutive vertical jumps protocol in sprinters measuring GCT, which involves vertical movements in consecutive, sports-specific actions like running performance demands. Therefore, this study aimed to verify the validity and reproducibility of five vertical jump test (5VJT) in elite Olympic and Paralympic sprinters. Additionally, we sought to identify possible differences between Paralympic athletes with different disabilities.

2 │ Methods

2.1 │ Study design and participants

The present research was a cross-sectional study. Forty-nine high-performance sprinters, 32 men and 17 women, participated in this study. Of these, 43 were Paralympic (19 with visual impairments, ten with cerebral palsy, eight leg amputees and six arm amputees) and eight non-disabled athletes. All participants were members of the national Paralympic team with over five years of elite training experience. Twenty-nine had competed in the Paralympic Games (London 2012, Rio 2016, or Tokyo 2020), and twenty were Paralympic medalists. The characterization of participants is detailed in Table 1.

2.2 │ Ethical consideration

All athletes were informed of the study's risks and benefits before data collection and signed an institutionally approved informed consent form according to the guidelines of the Ethical Committee of the Federal University of São Paulo, São Paulo, Brazil (UNIFESP; no 20429613.7.0000.5505).

2.3 │ Protocols

2.3.1 │ SJ

The SJ protocol involved performing a vertical jump from a half-squat position (knee flexion of approximately 110º) without prior countermovement. Athletes maintained a static position for 5 seconds before executing the jump [10].

2.3.2 │ CMJ

In this protocol, the athlete started standing with the trunk erect and knees extended. The vertical jump was performed using the countermovement technique, without upper limbs contributions, utilizing stretching-shortening cycle [knee flexion and extension] and maintaining extended knees during flight, as previously described by Bosco [24, 25].

2.3.3 │ 5VJT

In the 5VJT, the athletes executed five vertical jumps as high and quickly as possible, using the same technique as CMJ. They were instructed not to use their upper limbs to assist in propulsion, to keep their knees extended during the flight, and to land on the metatarsals rather than the entire surface of the foot [25]. Jump height values, and specifically GCT in the 5VJT protocol, were measured using the infrared optical system Opto Jump System (Microgate, Italy). The average of five consecutive heights and the four GCTs were used for analysis. Leg amputee athletes performed all jumps with their competition prostheses.

2.4 │ Data collection

Hypothesis of the present research was that the average height of five consecutive jumps would strongly correlate with the CMJ and SJ, and that GCT would be a sensitive and reproducible measure for elite Olympic and Paralympic sprinters. All athletes were evaluated at the beginning of the competitive season and performed the tests on the same day in the following order: SJ, CMJ, and 5VJT. Three attempts were made for each protocol, with a 30-second interval between attempts. Athletes were encouraged to exert maximum effort to achieve the highest possible jump height. A 40-minute break separated each protocol to minimize the effects of fatigue or potentiation from the previous test. Due to routine assessments at the training center, all athletes were familiar with the testing procedures. Before the tests, athletes performed a routine 20-minute warm-up, including light running, stretching, and mobility exercises. Before the second and third protocols, they were instructed to perform a light rewarm-up of 3 to 5 minutes.

2.5 │ Statistical Analysis

Data normality was assessed using the Kolmogorov-Smirnov test, and the homoscedasticity test was used to evaluate variance equality between samples when necessary. Average scores were used to compare results between methods, with analysis of variance (ANOVA) for repeated measures and the Tukey-Kramer post hoc test applied. Intraclass correlation test (ICC) and the coefficient of variation (CV = standard deviation [SD] / sample mean × 100) were used to evaluate jump height reliability across three attempts for each protocol. ICC values <0.50 were considered low, between 0.50 and 0.75 moderate, 0.75 and 0.90 good and >0.90 excellent [26]. Bland-Altman plots assessed agreement between methods (CMJ vs 5VJT and SJ vs 5VJT) [27]. A 95% limit of agreement (LOA) was calculated using the equation:

$$LOA = (1.96 \times SD) \pm \text{mean of differences}$$

Pearson correlation coefficients assessed the association levels between protocols (CMJ vs 5VJT, SJ vs 5VJT) and subgroups. Correlation was classified as very weak (0.0–0.2), weak (0.2–0.4), moderate (0.4–0.7), strong (0.7–0.9) and very strong (0.9–1.0) [28]. Effect sizes were calculated using eta square (η2), with $\eta^2 < 0.01$ indicating no effect; $0.01 > \eta^2 < 0.06$ indicating a small effect; $0.06 > \eta^2 < 0.14$ indicating a moderate impact and $\eta^2 > 0.14$ indicating a significant effect [29]. Statistical significance was set at $P<0.05$ for all comparisons. Statistical Package for the Social Sciences (SPSS) version 2.0 for Windows was used for statistical analyzes.

3 │ Results

Table 2 presents comparisons of jump height (cm) obtained through the three different methods. Significant differences were found in vertical jump height between all protocols in athletes with visual impairment ($P<0.010$). In leg amputee and cerebral palsy athletes, 5VJT showed significantly lower values compared to CMJ and SJ. Conversely, non-disabled athletes exhibited significantly higher CMJ values compared to SJ and 5VJT. Arm amputee athletes showed significantly lower SJ values compared to CMJ and 5VJT. Table 3 displays the reliability analysis of each method using ICCs and their upper and lower limit values. All methods demonstrated excellent reliability across all analyzed groups. The ICC and CV for GCT across groups (Table 3) showed good reliability for visual impairment (ICC=0.68, 95% confidence interval [CI]:0.72-0.64; CV=9.5%), leg amputees (ICC=0.72, 95% CI:0.78-0.64; CV=13.8%), good reliability for cerebral palsy athletes (ICC=0.77, 95% CI:0.18-0.72; CV=14.8%), and excellent reliability for arm amputees (CCI=0.94, 95% CI:0.95-0.93; CV=6.9%) and non-disabled athletes (ICC=0.93, 95% CI:0.94-0.93; CV=10.2%). Figure 1 illustrates Bland and Altman plots comparing 5VJT with CMJ and SJ within each group. These plots demonstrate low bias values with high agreement and a homogeneous distribution between the limits of agreement, indicating an absence of proportion bias. Table 4 presents agreement analysis for GCT during 5VJT across subgroups using ICCs. These data show low bias values with high agreement and homogeneous distribution between the limits of agreement, indicating the absence of proportion bias. Table 5 shows a robust correlation between vertical jump height across, while GCT demonstrated very weak to moderate correlations with 5VJT across different groups analyzed (Table 5). Table 6 presents the mean GCT values during 5VJT. ANOVA revealed no statistical differences between visual impairment and cerebral palsy athletes, and between arm amputees and non-disabled athletes. All other comparisons were statistically different. The effect size was analyzed using eta-squared ($F= 34.556$; $P\leq0.010$ and $\eta^2 = 0.03$ as a small effect).

Table 1. Characterization of the elite athletes participated in this study (N=49).

Groups	Gender (n)	Age (ys)	Weight (kg)	Height (cm)
Visual impairment	Male = 9 / Female = 9	28.6 (SD=5.8)	69.7 (SD=8.9)	172 (SD=11.3)
Leg amputees	Male = 4 / Female = 3	27.1 (SD=3.8)	72.5 (SD=7.3)	174 (SD=36.0)
Arm amputees	Male = 4 / Female = 2	31.5 (SD=8.3)	68.1 (SD=8.0)	172 (SD=15.5)
Cerebral palsy	Male = 7 / Female = 3	28.6 (SD=3.0)	72.1 (SD=4.6)	170 (SD=15.3)
Non-disabled	Male = 8 / Female = 0	34.8 (SD=6.0)	74.3 (SD=4.8)	178 (SD=0.4)

Table 2. Comparison of jump high between CMJ, SJ, and 5VJT (N=49).

Groups	CMJ (cm)	SJ (cm)	5VJT (cm)	P-value	η²	Effect size
Total	40.9 (SD=9.1) *	38.5 (SD=7.5)	38.6 (SD=9.6)	<0.010	0,01	Small
Visual impairment	39.5 (SD=6.6) **	37.8 (SD=5.9) ****	36.9 (SD=6.2)	<0.010	0.02	Small
Leg amputees	28.8 (SD=4.5)	28.1 (SD=4.9)	26.5 (SD=4.2) ***	<0.010	0.04	Small
Arm amputees	51.0 (SD=9.8)	46.2 (SD=9.2) *****	50.9 (SD=8.0)	<0.010	0.02	Small
Cerebral palsy	36.8 (SD=7.9)	35.5 (SD=6.9)	33.8 (SD=7.0) ***	<0.010	0.02	Small
Non-disabled	48.8 (SD=6.3) **	45.3 (SD=6.5)	45.3 (SD=5.8)	<0.010	0.06	Medium

Values are presented as mean (SD).
***** CMJ is different from SJ and 5 VJT.
****** CMJ is different from SJ and 5 VJT.
******* 5VJT is different from CMJ and SJ.
******** SJ is different from 5 VJT.
********* SJ is different from CMJ and 5VJT.
η^2: eta-squared.

Table 3. Reliability analysis results for jump height in SJ, CMJ, and 5VJT and GCT for 5VJT based on absolute agreement of ICC and 95%CI (N=49).

	CMJ		SJ		5VJT		GCT	
	ICC	**95%CI**	**ICC**	**95%CI**	**ICC**	**95%CI**	**ICC**	**95%CI**
Total	0.96	0.96 to 0.97	0.89	0.87 to 0.90	0.98	0.97 to 0.98	0.59	0.50 to 0.68
Visual impairment	0.98	0.98 to 0.99	0.87	0.87 to 0.90	0.97	0.97 to 0.98	0.68	0.64 to 0.72
Leg amputees	0.97	0.96 to 0.98	0.81	0.75 to 0.86	0.94	0.91 to 0.95	0.72	0.64 to 0.78
Arm amputees	0.99	0.98 to 0.99	0.94	0.92 to 0.95	0.98	0.98 to 0.99	0.94	0.93 to 0.95
Cerebral palsy	0.98	0.97 to 0.98	0.92	0.91 to 0.94	0.98	0.97 to 0.98	0.77	0.72 to 0.81
Non-disabled	0.98	0.98 to 0.98	0.87	0.85 to 0.88	0.96	0.95 to 0.97	0.93	0.93 to 0.94

4 │ Discussion

This study aimed to verify the validity and reproducibility of the 5VJT protocol as a more specific assessment tool for elite Olympic and Paralympic sprinters. Although higher values were found in the CMJ (40.9 [SD=9.1] cm) compared to SJ (38.5 [SD=7.5 cm]) and 5VJT (38.6 [SD=9.6 cm]), reliability analysis demonstrated that the 5VJT test is equally valid for measuring jump height compared to CMJ and SJ.

These differences can be attributed to the elastic component and motor coordination required for different types of jumps. According to Anderson & Pandy (1993) [30], during CMJ, the strain energy stored in elastic tissues primarily comes from the gravitational potential energy of the skeleton and proximal extensor muscles during the eccentric phase of the squat. In contrast, during SJ, energy stored in elastic tissues primarily derives from contractile elements as they lengthen the muscles' tendons and series elastic elements, with a reduced contribution from contractile elements to the skeleton.

The second objective was to identify differences between Paralympic athletes with various disabilities. Similar trends were observed in visual impairment, arm amputees, and non-disabled athletes, consistent with the findings of Pereira et al., (2022) [31] in sprinters with visual impairment (SJ = 35.9 [SD=6.3] cm; CMJ=38.5 [SD=6.2 cm]) and non-disabled athletes (SJ=45.6 [SD=3.2] cm; CMJ=46.7 [SD=4.0] cm). However, this pattern was not observed in cerebral palsy and leg amputee athletes, likely due to their morphological and functional characteristics.

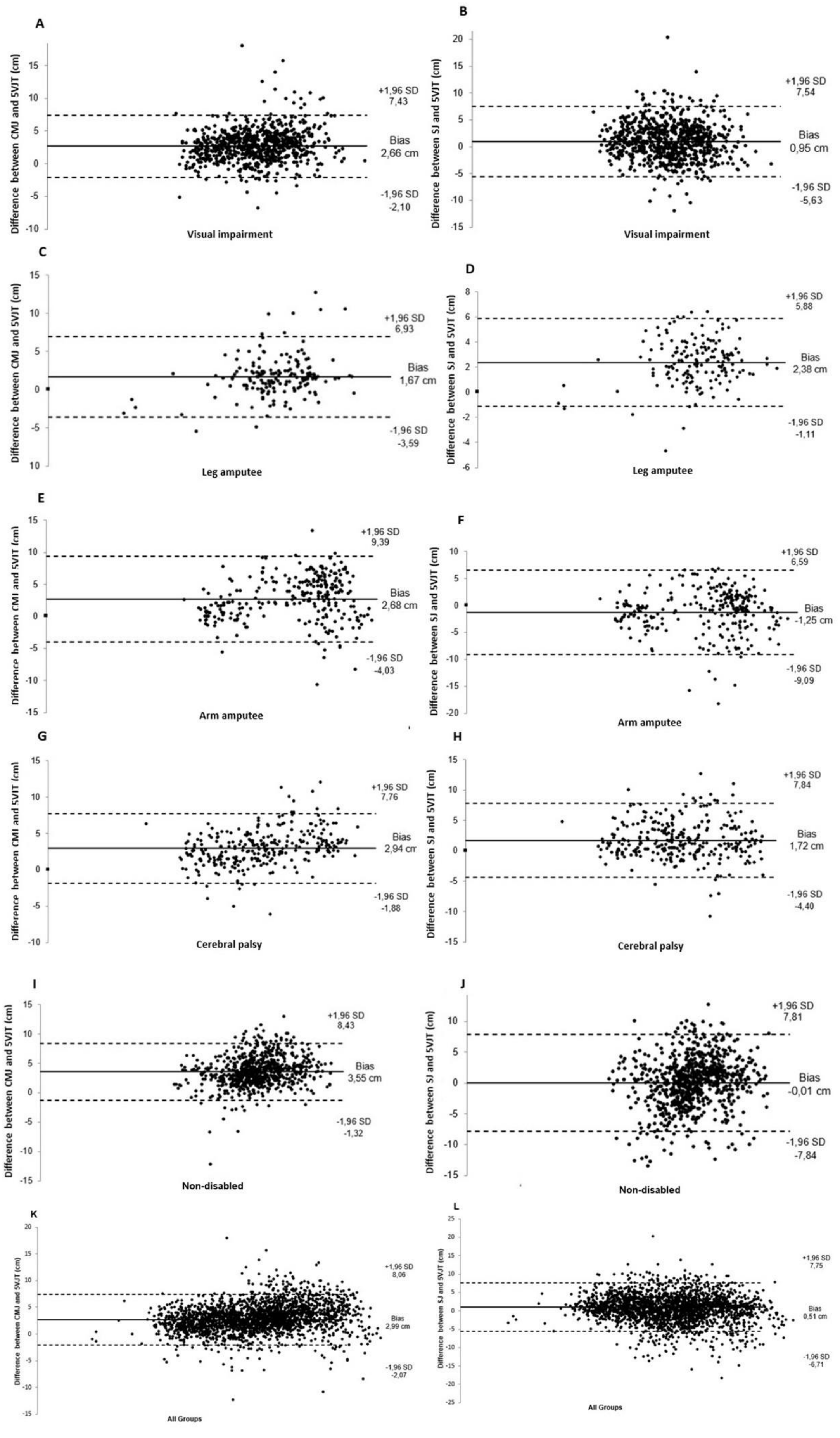

Figure 1. Bland and Altman graph for comparisons between 5VJT with CMJ and SJ within each subgroup. Figures A and B show comparisons for athletes with visual impairment, C and D for arm amputees, E and F for leg amputees, G and H for athletes with cerebral palsy, I and J for non-disabled athletes and K and L for average of all groups.

Table 4. Agreement values for GCT during 5VJT repetitions between the groups analyzed (N=49).

Groups	Mean of differences (ms)	Upper limit (ms)	Lower limit (ms)
Visual impairment × Arm amputees	0.04	0.26	-0.16
Visual impairment × Leg amputees	0.01	0.36	-0.33
Visual impairment × Cerebral palsy	0.01	0.28	-0.25
Visual impairment × Non-disabled	0.04	0.26	-0.18
Arm amputees × Leg amputees	-0.03	0.25	-0.32
Arm amputees × Cerebral palsy	-0.01	0.15	-0.18
Arm amputees × Non-disabled	-0.003	0.11	-0.12
Leg amputees × Cerebral palsy	0.01	0.33	-0.3
Leg amputees × Non-disabled	0.03	0.33	-0.27
Cerebral palsy × Non-disabled	0.02	0.25	-0.21

Table 5. The correlation coefficient between 5VJT, CMJ, SJ, and GCT in 5VJT within each subgroup (N=49).

		Visual impairment	Leg amputees	Arm amputees	Cerebral palsy	Non-disabled
	SJ	0.85 *				
Visual impairment	CMJ	0.93 *				
	GCT	0.22 *				
	SJ		0.84 *			
Leg amputees	CMJ		0.92 *			
	GCT		-0.08			
	SJ			0.90 *		
Arm amputees	CMJ			0.93 *		
	GCT			-0.25 *		
	SJ				0.90 *	
Cerebral palsy	CMJ				0.95 *	
	GCT				-0.47 *	
	SJ					0.80 *
Non-disabled	CMJ					0.92 *
	GCT					0.06

***** $P<0.05$

Table 6. Mean GCT during the 5VJT between groups (N=49).

	Visual impairment	Arm amputees	Leg amputees	Cerebral palsy	Non-disabled	P-value
GCT (seconds)	0.63 (SD=0.06) *	0.58 (SD=0.04) **	0.65 (SD=0.18) ***	0.61 (SD=0.09) *	0.59 (SD=0.06) ****	<0.010

Values are presented as mean (SD).

***** Visual impairment, cerebral palsy, different from arm amputees, leg amputees, and non-disabled.

****** Arm amputees are different from visual impairment, leg amputees, and cerebral palsy.

******* Leg amputees are different from all.

******** Non-disabled different from visual impairment, leg amputees and cerebral palsy.

In cerebral palsy athletes, structural alterations in sarcomeres, such as a reduced number of units in series, increased extracellular matrix content, and heightened passive mechanical stiffness of the fibers, may impair the muscle's ability to use elastic energy [32]. This could explain this group's inverse relationship between GCT and jump height.

From leg amputee athletes, the inability to utilize ground reaction force effectively on the prostheses and increased GCT to protect the unaffected limb may disrupt stability and joint movement, leading to lower jump heights compared to CMJ and SJ [33].

The 5VJT analysis revealed excellent reproducibility for jump height and moderate reproducibility for GCT. The ICC results for height were consistent with those reported by Dal Pupo et al., (2014) [34], for multiple jump tests in non-disabled athletes, and superior to those found in athletes with visual impairment [35], cerebral palsy [36] and non-disabled athletes [37]. GCT showed moderate reliability in visual impairment and leg amputee athlete, and good to excellent reliability in cerebral palsy, arm amputee, and non-disabled athletes. This suggests that more minor impairments may result in more excellent reliability.

When analyzed separately, the heterogeneous results for 5VJT may be attributed to the differences in movement strategies adopted during consecutive jumps, where athletes aim for more economical movement patterns to minimize fatigue and energy expenditure [38]. Peripheral metabolic changes can trigger responses from groups of group III/IV muscle afferent neurons affecting locomotor performance, which may inhibit central neuromotor production and influence neuromuscular fatigue [39-41].

Thus, analyzing GCT during the 5VJT protocol provides a new perspective. Despite no change in acceleration capacity, Vial et al., (2023) [42] demonstrated that peripheral fatigue increases GCT and vertical impulse in football players. This adaptation helps maintain horizontal speed but may indicate more significant fatigue in hip extensors [i.e., the gluteal and hamstring muscle groups], potentially explaining the increased risk of hamstring muscle injuries [43-45].

This study’s analysis of GCT during 5VJT showed moderate overall reliability (ICC=0.59) and excellent agreement in specific groups. However, visual impairment and leg amputee athletes exhibited moderate reliability, possibly due to balance and coordination challenges [46, 47].

4.1 │ Limitations

A limitation of this study is the lack of verification of associations between 5VJT results and actual performance. Future research should address this gap to confirm these findings in Olympic and Paralympic sprinters or other sports contexts.

5 │ Conclusions

These findings suggest that the 5VJT is a reliable tool for measuring jump height and GCT, offering practical information for sports scientists and coaches about two key variables to monitor performance and muscle fatigue [i.e., jump height and contact time] in the same protocol. This validation supports a better understanding of athletic performance and can inform the development of personalized and effective training strategies (i.e. training load control) in athletes with and without disabilities.

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Authors’ contributions

Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work: TFL, RVJ, OTJ, AV, JPCS, CWF; Drafting the work or revising it critically for important intellectual content: TFL, RVJ, OTJ, AV, JPCS, CWF; Final approval of the version to be published: TFL, RVJ, OTJ, AV, JPCS, CWF; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: TFL, RVJ, OTJ, AV, JPCS, CWF.

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Ethics approval and consent to participate

All athletes were informed of the study's risks and benefits before data collection and signed an institutionally approved informed consent form according to the guidelines of the Ethical Committee of the Federal University of São Paulo, São Paulo, Brazil (UNIFESP; no 20429613.7.0000.5505).

Competing interests

We do not have potential conflicts of interest with respect to the research, authorship, and publication of this article.

Availability of data and materials

The datasets used during the current study are available from the corresponding author on request.

Using artificial intelligent chatbots

None.

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