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Vertical jump performance in athletes with cerebral palsy
Rendimiento en salto vertical en atletas con parálisis cerebral

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Abstract. The principal difference between an Olympic and a Paralympic sport is the classification structure of the sports in which the athlete competes. The Paralympic Classification System subsidizes such a structure. This study aimed to investigate possible height differences in six vertical jumps in Para athletics athletes with cerebral palsy from classes T35 to T38 to contribute to the Paralympic Classification System. They participated in this study, and forty-one athletes were divided into the experimental group (thirty-five with cerebral palsy T35= 6; T36= 10; T37 = 12; T38 = 7) and the Control Group. The athletes were evaluated using the OptoJump Next equipment (OJ). The protocol sequence of the Vertical Jump battery included squat jump, single left leg one jump, single right leg one jump, both leg seven jumps, single left leg seven jumps, and single right leg seven jumps. We found significant differences between all classes and the control group ($p<0.001$). This study indicates that the battery of vertical jump tests not only identifies the athletes' eligibility but also helps to allocate different classes of athletes with cerebral palsy. To develop a technical assessment that contributes to implementing evidence to the Classification System of World Paralympic Athletics - WPA.
Keywords: Para athletics; evidence-based classification, jump test, and cerebral palsy.

Resumen. La principal diferencia entre un deporte olímpico y uno paralímpico es la estructura de clasificación de los deportes en los que compite el atleta. El Sistema de Clasificación Paralímpica subvenciona tal estructura. Este estudio tuvo como objetivo investigar las posibles diferencias de altura en seis saltos verticales en atletas de Para atletismo con parálisis cerebral de las clases T35 a T38 para contribuir al Sistema de Clasificación Paralímpica. Participaron en este estudio cuarenta y un atletas, divididos en el grupo experimental (treinta y cinco con parálisis cerebral T35= 6; T36= 10; T37 = 12; T38 = 7) y el Grupo Control. Los atletas fueron evaluados utilizando el equipo OptoJump Next (OJ). La secuencia del protocolo de la batería de Salto Vertical incluía salto en cuclillas, salto con una sola pierna izquierda, salto con una sola pierna derecha, saltos con ambas piernas de siete saltos, saltos con una sola pierna izquierda de siete saltos y saltos con una sola pierna derecha de siete saltos. Se encontraron diferencias significativas entre todas las clases y el grupo de control ($p<0,001$). Este estudio indica que la batería de pruebas de salto vertical no solo identifica la elegibilidad de los atletas, sino que también ayuda a asignar diferentes clases de atletas con parálisis cerebral. Con el fin de desarrollar una evaluación técnica, contribuyendo a la aplicación de pruebas al Sistema de Clasificación del Atletismo Paralímpico.
Palabras clave: Para atletismo; clasificación basada en la evidencia, test de salto, y parálisis cerebral.

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Introduction

The primary difference between an Olympic and a Paralympic is the classification structure of the sports in which the athlete competes. Such structure is subsidized by the Paralympic Classification System (PCS), which uses medical classification as the first concept to assess an athlete's disability. A considerable change in the PCS occurred in 1988 regarding the view on impairment and valuing and considering the specific gestures inherent to each sport; this created the concept of Functional Classification Systems (FCS) (Strohkendl, 1986). The second modification was the adoption of Evidence-Based Classification in Paralympic Sports (EBCPS), intending to subsidize the FCS to group different impairments and minimize function variability in the sports gestures within each sports class. However, it is currently essential to establish relevant technical questions for the PCS associated with EBCPS (Beckman & Tweedy, 2009; Tweedy & Vanlandewijck, 2011; Tweedy et al., 2012). The PCS used in Para athletics requires that athletes with physical impairment meet at least one of the eight minimum criteria for clinical eligibility impairment (2015). These eight are hypertonia, athetosis, ataxia, limb deficiency, impaired passive range of movement, impaired muscle power, leg length difference, and short stature. These subdivisions resulted in 50 sports classes with specific characteristics (International Paralympic Committee, 2018). This study was limited to the first three conditions associated with brain lesions, including cerebral palsy - CP.

The World Para Athletics is concerned about maintaining competitiveness between classes and seeks to maintain competitive equity so that differences in the athletes' functional potential do not determine athletic success. Therefore, the process of PCS structuring must have scientific evidence.

In this sense, it is still possible to find few studies in the current literature that seek to sustain the separation of sports classes. These studies have analyzed and compared the performance of athletes with different levels of lower limb impairment who are using prosthetics or not, on which

changes in sprint races after the Rio 2016 Paralympic Games could be based (Hassani et al., 2014; Hassani et al., 2015; Potthast et al., 2016). Although studies show that, in some paralympic sports, the different classes do not interfere with physical performance (Luarte et al., 2022). Studies with a control group made up of athletes without disabilities compared to athletes with cerebral palsy make it possible to identify not only the difference in the behaviour of the results but also the motor adjustments made. (Runciman et al., 2014).More studies are needed to understand the class system in Para athletics.

Despite the importance of science in the classification process of Para athletics, Connick et al. (2016) is the only study currently used by Para athletics to establish the Maximum Allowable Standing Height (MASH) of athletes with bilateral lower limb disability belonging to T/F61 male and T/F62 male and female classes.

Other studies on athletes with cerebral palsy (CP) have been conducted in classes T35 to T38 to evaluate the influence of isometric strength (Beckman et al., 2016), coordination, and movement speed in a race (Connick et al., 2015). These studies followed the proposal by Beckman et al. (2014) and Beckman & Tweedy (2009), which presented a battery of physical tests to evaluate muscle strength and motor coordination validated for people without disabilities. However, these studies have validated some tests only in individuals without or with mild impairment.

As for a sport's specific functionality and efficiency, vertical jump (VJ) tests are crucial in evaluating and predicting the performance of Olympic and Paralympic sprinters (Loturco et al., 2015; Loturco et al., 2018). In this way, the VJ tests are part of the evaluation protocol of World Para Athletics PCS (International Paralympic Committee, 2018). Nevertheless, no studies compare VJ performance in different CP classes (T35 to T38). In this sense, the aim of this study was to investigate the performance of six types of VJ in Para athletes with CP from classes T35 to T38.

Materials and methods

Participants

This study included 41 male athletes, 35 with CP and six without impairment. They were split into the Control Group (CG), composed of athletes without impairment, and the experimental group (Athletes with CP). All athletes with CP were finalists in the Brazilian Para athletics Championships. CG comprised Guide Athletes of athletes with visual impairment at the Brazilian National Para Athletics Team.

Table 1.
Demographics of the participants.

Class	Description of the impairment	N	Age (yr)	Mass (Kg)	Height (cm)	BMI (kg/m²)	Athletics experience (yr)
T35	Hypertonia (Diplegic)	6	23.00 ±7.19	61.63 ±6.41	169.33 ±5.89	21.55 ±2.53	3.16 ±1.67
T36	Involuntary movement or incoordination (Athetosis or Ataxia)	10	27.80 ±6.6	60.09 ±10.38	171.00 ±10.02	20.46 ±2.18	5.90 ±2.78
T37	Hypertonia (Hemiplegic)	12	23.08 ±4.80	65.20 ±9.88	173.66 ±5.81	21.53 ±2.09	5.41 ±3.20
T38	Minimum Impairment Criteria (MIC)	7	30.00 ±8.16	71.67 ±11.12	175.00 ±4.88	23.31 ±2.60	7.00 ±5.91
Control Group	Non-disabled	6	30.66 ±7.36	74.00 ±9.30	174.83 ±6.09	24.15 ±1.95	16.50 ±5.89

BMI, Body Mass Index.

Research ethical aspects

All athletes signed an Informed Consent Form following the ethical standards of scientific research involving human beings, nº 466/2012, approved by the Human Research Ethics Committee of the UNICAMP (nº 2144713/2017).

Procedures

The data were collected in 2018 during the Brazilian Para Athletics Championships. Standardized warm-up exercises included a five-minute self-paced low-intensity run, skipping exercises, and two 10-meter sprints. The battery sequence of VJ included a squat jump (SJ), a single left leg one jump (SL1J), a single right leg one jump (SR1J), both legs seven jumps (B7J), single left leg seven jumps (SL7J), and single right leg seven jumps (SR7J).

Vertical jumps Battery

The athletes were evaluated using the OJ equipment. This system uses electric photocells (Microgate, Bolzano, Italy) to measure flight time (t). It estimates the height of the rise of the body's center of gravity (h) during VJ (i.e., h = gt2/8, where g = 9.81 $m \cdot s^{-2}$). The same evaluator conducted all the tests to avoid procedural data collection errors and provide the same conditions for all participants.

They had three trials in each protocol, and the best attempt was used for data analysis. All participants performed familiarization trials before the experimental evaluation and executed the attempts without assistance. They had two minutes of recovery time between each protocol and 30 seconds between jumps.

Squat jump

The protocol followed that of Pereira et al. (2016). Before the attempt, athletes were instructed to stay in a static position with their knees bent at an angle of approximately 90º for two seconds without any preparatory movement. They performed the SJs with their hands on their hips to avoid using the upper limbs during the jump.

Single leg one jump

Each participant performed the jump with one leg, starting with the left foot (SL1J) of the designated testing leg on the OJ and repeating the same procedure with the right leg (SR1J). A participant was instructed to quickly sink

to a self-selected depth and jump as high as possible. A participant was allowed to use his/her arms freely during the test. There was no standardization for positioning the uninvolved leg to ensure a more natural movement pattern. The left and right legs were assessed separately (Young et al., 2001).

Both legs have seven jumps (B7J)

Athletes were instructed to jump seven consecutive times, with both legs reaching the highest possible height in each attempt, continuously between landing and take-off phases. They were allowed to use their arms during the test. Both leg tests were considered successful if an athlete could land, stabilize, and jump another time.

Single leg seven jumps

Athletes were instructed to jump seven consecutive times with only one leg reaching the highest possible height in each attempt, in a continuous process between landing and take-off phases to improve balance (Hardesty et al., 2017). They were allowed to use their arms during the test. There was no standardization for positioning the uninvolved leg to ensure a more natural movement pattern. Athletes started with the left foot (SL7J) of the designated testing leg on the OJ and repeated the same procedure with the right leg (SR7J). A single-leg test was successful if an athlete could land with the same jump-leg, stabilize, and jump another time.

Both legs and single-leg tests were considered unsuccessful when a participant touched the floor with the contralateral lower or upper extremities, lost balance, or needed an additional short jump after the initial landing. The validating criteria for the test were adapted from Arden et al. (2011).

The mean height of seven jumps was used for data analysis. The number of jumps in both protocols was adapted from the World Para Athletics Classification Rules and Regulation, which recommends the execution of five or more repeated jumps (International Paralympic Committee, 2018). The tests were recorded on a GoPro camera to analyze and control the jump phases, and the OJ system synchronizes the jump and video results for better analysis.

Statistical Analyses

The Shapiro-Wilk test was used to test the normality of data. The analysis of variance for repeated measurements (one-way ANOVA) was used with Tukey's post hoc to evaluate possible differences in variables between groups. A p-value of ≤0.05 was used to show possible significant differences. The Prism 8 for macOS version 8.2.1 (GraphPad Software, Inc.) software was used for all analyses. Data were presented in mean (M) and standard deviation (SD).

Results

The results showed significant differences between all classes and the CG ($p<0.001$). We also found lower values of SJ in T35 (21.25 ± 5.88 cm; $p=0.004$) when compared to T37 (29.84 ± 4.82 cm) and T38 (30.77 ± 7.14 cm) and in T36 (22.69 ± 8.86 cm; $p=0.009$) when compared to T37 and T38. Furthermore, no difference was found between T37 and T38 ($p<0.786$). The data from the single-leg one jump protocol revealed significant differences between all classes and the control group (32.98 ± 3.50 cm; $p<0.001$), except between T38 (SL1J = 18.65 ± 5.94 cm; $p<0.07$). The T35 (SR1J = 9.70 ± 7.91 cm; SL1J = 7.63 ± 3.23 cm; $p=0.004$) and T36 (SR1J = $9.59 \pm 5,87$ cm; SL1J = $10.69 \pm 6,51$ cm; $p=0.006$) have showed lower values when compared to T38 (SR1J = 18.30 ± 5.33 cm; SL1J = 18.65 ± 5.94 cm) in both legs and in relation to T37 on in the left leg (SL1J = 19.34 ± 7.78 cm; $p=0.004$). These data are shown in Figure 1. The data from the seven jumps protocol are presented in Figure 2. In this protocol, significant differences between all classes and the control group (CG = 44.15 ± 8.89 cm) were found ($p<0.001$), but no differences were found between classes (T35 = 13.13 ± 5.28 cm; T36 = 14.64 ± 6.58 cm; T37 = 19.40 ± 10.29 cm; T38 = 18.42 ± 7.26 cm; $p>0.05$). The T36 (SR7J = 2.74 ± 4.37 cm; SL7J = 3.43 ± 3.02 cm; $p<0.001$) showed lower values when compared to T37 (SR7J = 9.03 ± 3.14 cm; SL7J = 13.29 ± 6.53 cm) and T38 (SR7J = 9.97 ± 2.0 cm; SL7J = 11.73 ± 3.29 cm). Otherwise, the T35 (SL7J = 3.72 ± 3.11 cm; $p<0.001$) showed lower values than T37 and T38 on the left leg.

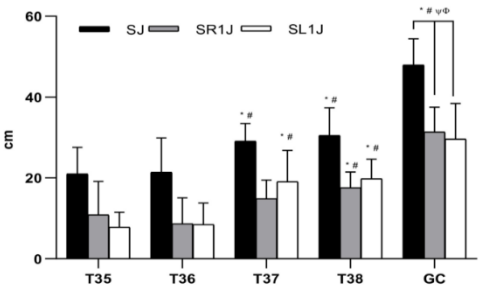

Figure 1. Mean (±SD) of vertical jump heights from squat jump with both right and left legs from cerebral palsy athletes and control group. SJ -Squat Jump; SR1J – Single Right Leg One Jump; SL1J -Single Left Leg One Jump; B7J– Both Legs Seven Jumps; SR7J– Single Right Leg Seven Jumps; SL7J – Single Left Leg Seven Jumps; * - $p<0.05$ in comparison to T35; # - $p<0.05$ in comparison to T36; Ψ - $p<0.05$ in comparison to T37; Φ - $p<0.05$ in comparison to T38.

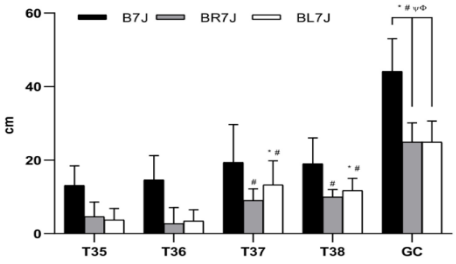

Figure 2. Mean (±SD) of seven jump protocol with both right and left legs from cerebral palsy athletes and control group. B7J– Both Legs Seven Jumps; SR7J– Single Right Leg Seven Jumps; SL7J – Single Left Leg Seven Jumps; * - $p<0.05$ in comparison to T35; # - $p<0.05$ in comparison to T36; Ψ - $p<0.05$ in comparison to T37; Φ - $p<0.05$ in comparison to T38.

Discussion

This study aimed to investigate the performance of six types of VJ in Para athletes with CP from classes T35 to T38. The main finding was a significant difference in VJ height between all evaluated classes and the CG in all protocols. These data corroborated the findings of Yanci et al. (2016) and Reina et al. (2018), who evaluated seven-a-side football athletes with brain injury, and Runciman et al. (2016), who compared athletes from classes T37 and T38 with the South African field hockey team. The difference could be attributed to the lower muscle strength generation capacity caused by impairment in the central nervous system and first motor neuron related to CP athletes' motor coordination deficit. In addition, the difference can be presented as hypertonia, athetosis, and ataxia, generating a deficit of motor coordination and balance during movement execution (International Paralympic Committee, 2018).

As presented in this study, the VJ is a practical test for PCS use. In addition, the association of this phenomenon with technological equipment provides quantitative information that minimizes the subjectivity of the current classification process. In this sense, we have found that different VJ protocols showed significant differences between athletes with a minimum criterion of impairment (T38) and the CG and between classes T35 vs. T38 and T36 vs. T38. These data indicate that SJ and a single unilateral jump may be used to differentiate borderline athletes between classes T35 vs. T38 and T36 vs. T38. In addition, the seven unilateral jumps allowed differentiation between classes T36 vs. T38. Such standards may be associated with the importance of unilaterally evaluating CP athletes for the PCS (Reina et al., 2020).

These findings may be justified by the different clinical profiles of the classes presented in the World Para Athletics Classification Rules and Regulation (2018), where there is a specific movement pattern for athletes in class T35 with hypertonia in both lower limbs (diplegic). In class T36, a general lack of coordination of movements (athetosis and ataxia) is associated with co-contraction in spastics CP (Damiano et al., 2000). These characteristics are also found in athletes of class T38 but with a lower degree of impairment.

We also found no significant differences between T37 class athletes with hemi-body hypertonia (hemiplegic) and T38 athletes. These findings may result from low VJ sensitivity to detect differences in the ability to generate muscle strength between the patterns presented by athletes in these classes, reinforcing the necessity of other studies to find protocols more sensible to detect specific differences between these classes.

The B7J test results also showed no significant difference between classes. This characteristic can be due to the low cushioning functionality in the jump landing phase for athletes with brain injury (Cámara et al., 2013). The single leg jump test analysis showed no difference between classes T35 and T36. However, the lowest height found in T35 and T36 compared to T37 and T38 may be due to gross motor coordination impairment in both classes (T35 and T36). These data are similar to the one found with those found by Reina et al. (2020), who have associated the functional loss of dynamic balance with the constant transition between the take-off and landing phases.

The first step of an efficient classification system is determining the eligibility of athletes who can practice the sport analyzed. In this sense, the results add evidence to the classification system of Para Athletics by showing that all groups of athletes with CP significantly differ in height concerning CG. However, despite the second step, which is as essential as eligibility, is to allocate athletes to functional classes, thereby making competitions as fair as possible, our data support the allocation only between T35 vs T38 and T36 vs T38. These findings open the opportunity for future studies analyzing another protocol that should develop the WPA classification manual based on evidence.

Conclusion

In conclusion, this study indicates that the VJ should be used as an objective tool for reliable devices to differentiate between athletes without impairment and those with cerebral palsy through quantitative data. This contributes to allocating different classes to this impairment group and developing a technical assessment part of an evidence-based classification of the Paralympic Classification System in World Para Athletics.

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