Dynamic and static stability in para-athletes with cerebral palsy considering their impairment profile

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Abstract
Background: Balance impairment is a common feature in people with cerebral palsy (CP), affecting the performance of daily-life and physical activities.
Objectives: To (1) explore the absolute and relative intrasession reliability of two balance tests to assess dynamic and static balance in ambulant para-athletes with CP; (2) explore the relationships between the two balance tests to determine potential application in sport classification; (3) assess the differences between CP profiles (ie, spastic diplegia, athetosis/ataxia, and spastic hemiplegia) in comparison to those with a minimum impairment; and (4) compare the outcomes of the static and dynamic balance of ambulant para-athletes with CP regarding controls.
Methods: A group of 129 male well-trained para-footballers with CP, classified as Level I according to the Gross Motor Function Classification System, participated in the present study. Static balance was assessed using the One-Leg Stance test, performed bilaterally on a force platform, and the dynamic balance was assessed in two conditions of the Tandem Walk test (TW): walking heel-toe contact over a 5-m straight line and performing 10 steps.
Results: Moderate-to-excellent intrasession reliability (intraclass correlation coefficient = 0.60–0.98) was obtained for all the measurements and groups. However, only small to moderate correlations were found between the dynamic and the static measurements of balance for the CP group when performing the One-Leg Stance test with the unimpaired or dominant leg (0.23 < r < 0.30; P < .01). The TW performed over 10 steps revealed more sensitivity to discriminate between CP profiles. Those para-athletes with ataxia/athetosis performed worse in all the tests whereas all CP profiles performed worse than the control group (P < .01).
Conclusions: Balance performance and postural control are constrained to a higher extent in those with impaired voluntary control due to ataxia or with involuntary contractions of the muscles due to athetosis.

INTRODUCTION

Cerebral palsy (CP) is a group of permanent disorders of motor impairment caused by a nonprogressive injury in the developing brain.1 People with CP are a heterogeneous population who experience a wide range of impairments affecting their movement and posture,2 including abnormal muscle tone (ie, higher muscular stiffness), muscle weakness, random and uncontrolled body movements, and balance and coordination problems.3,4 According to the Surveillance of Cerebral Palsy in Europe,5 CP is divided into different subtypes depending on the dominant neurological signs: spastic (ie, abnormal pattern of posture and/or movement, increased tone, and pathological reflexes), dyskinetic (both abnormal patterns of posture and/or...
movement and involuntary, uncontrolled, recurring, occasionally stereotyped movements), or ataxic (ie, both abnormal patterns of posture and/or movement and loss of orderly muscular coordination so that movements are performed with abnormal force, rhythm, and accuracy).

In clinical and research contexts, motor function in people with CP is commonly evaluated through the Gross Motor Function Classification System (GMFCS). This classification system clusters individuals into five groups according to their motor proficiency, from Level I (ie, independent movement; lowest impairment level) to Level V (ie, complete assistance is required; highest impairment level). For those classified in Level I, the GMFCS states that they can “perform gross motor skills such as running and jumping but speed, balance, and coordination are limited.” However, in the sports context, gross motor function, including the balance of individuals with CP, has traditionally been evaluated using the Cerebral Palsy International Sport and Recreation Association (CPISRA) classification system.7 The CPISRA system groups para-athletes into eight sport classes according to their impairment and motor capabilities. Classes 1 to 4 are for those who need a wheelchair to perform any sport or physical activity (ie, those who have impaired hands/arms/trunk function, including sitting balance), and classes 5 to 8 are for ambulant para-athletes (5: “moderate” spastic diplegia, 6: “moderate” athetoid/ataxic profile, 7: “moderate” spastic hemiplegia, and 8: “mild” impairment of the aforementioned CP profiles).8 This classification system has been used for both exercise management in people with CP and classification purposes; that is, it has been applied for the last three decades in Paralympic sports such as para-athletics (classes 1 to 8), boccia (classes 1 and 2), and CP football (classes 5 to 8). In both classifications, used for the categorization of the sample of this study, balance is included as a key observational feature.

Balance deficits are among the symptoms having a more profound impact on motor function and quality of life in all CP profiles.9 Presenting a poor balance reduces the ability to perform gait-related activities10 and increases the risk of falling,11 which, in turn, limit participation in daily activities, including sports and physical activities.12 Also, it has been demonstrated that individuals with CP who have less severe impairment tend to present better balance than those with more severe impairment.13 Balance is commonly evaluated in static and dynamic condition. Static balance is defined as the ability to maintain the line of gravity (vertical line from the center of mass) of a body within the base of support (BoS) with minimal postural sway. Conversely, dynamic balance consists of the ability to move the center of pressure (CoP) within the BoS and to move CoP from a BoS to another BoS.14 The timed unipedal stance test (also referred to as timed single-limb stance, unipedal balance test, one-leg stance test, or one-leg standing balance) is a simple test for measuring individuals’ static balance.15 In clinical research settings, gold-standard measurements for static standing balance are typically conducted in motion labs using force plates, where the CoP sway is registered providing the most accurate assessment.16 On the contrary, in the sport context, such as classification of para-athletes with CP, access to technological assessment equipment (eg, force platforms) is very limited. Thus, balance is usually assessed by counting the number of seconds that the para-athlete can achieve or keep the balance and/or observing their postural adjustments during the test. However, this approach cannot be regarded as an appropriate method of assessment because it does not provide information of great relevance to identify aspects of motor impairment in people with CP.17 In fact, the analysis and identification of the CoP fluctuations (ie, trajectory, velocity, and amplitude) help to understand what is happening while the test is being performed.18 Concerning the evaluation of dynamic balance, the literature has used observational scales to evaluate gait tasks19 or a variety of quantitative tests where participants have to perform a functional mobility task with high balance demands (ie, standing-up, walking, turning).20 Among them, the tandem walking test (TWT) is a test included in neurologic examination routines to assess dynamic balance to indicate potential neuromotor limitations, as it represents a major challenge to individuals with CP.21 This test requires walking forward along a taped line, placing one foot directly in front of the other, as per the heel of one foot directly in front and in contact with the toes of the contralateral foot.22 The TWT outcomes are based on qualitative (ie, large body sway or identification of balance strategies) or quantitative data (ie, the number of “out steps,” number of steps to cover a distance and/or the time required to accomplish the test).21

Although static balance tests are easy to standardize, its impact on the dynamic balance in ambulant para-athletes with CP is unclear, especially on those with high motor proficiency. In general terms, the literature is controversial. On the one hand, larger CoP oscillations shown during static tests (ie larger postural sway) have been related to a worse dynamic balance ability.23 On the other hand, other studies showed that an increase in the postural sway is not necessarily an indicator of poor dynamic balance.24 It must be pointed out that these controversial results can be related to the fact that many of the available studies have been carried out in different population such as people with stroke, older adults, or children with CP. Thus, little is known about balance proficiency in adults with CP according to different CP profiles or about whether balance assessments can be implemented for classification purposes in ambulant para-athletes with eligible impairments of hypertonia, ataxia, or athetosis. In addition, in para-sport classification, impaired balance has
been traditionally assessed using static balance tests (eg, one leg stance), but most sport skills (ie, activity limitation) are performed in dynamic conditions. Therefore, it is necessary to apply valid, reliable, accurate, and ratio-scaled assessment methods to assess balance not only in static but also in dynamic conditions (eg, the TWT) that can be used for assessing different CP profiles.25

Based on the aforementioned gaps of the literature, the aims of this study were to (1) explore the absolute and relative intrasession reliability of two balance tests to assess static and dynamic balance in ambulant para-athletes with CP; (2) explore the relationships between the two balance tests to determine the potential application in para-sport classification; (3) assess the differences between CP profiles (ie, spastic diplegia, athetosis/ataxia, and spastic hemiplegia) in comparison to those with a minimum impairment; and (4) compare the outcomes regarding the static and dynamic balance of ambulant para-athletes with CP with the outcomes of able-bodied athletes (ie, control group).

METHODS

Participants

A group of 129 male para-footballers with CP participated in the present study, all of them classified as Level I according to the GMFCS.10 With regard to their CP profiles,5 8.5% had spastic diplegia (n = 11), 14.7% with ataxia/athetosis (n = 19), and 62.8% with spastic hemiplegia (n = 81) (Table 1). The remaining 14.0% were categorized as minimum impairment (n = 18) of hypertonia (ie, spasticity grade 1-2 in at least one lower limb); ataxia (ie, clear signs of cerebellar dysfunction; tremor or dysmetria on the finger-nose test, finger-nose-finger test, or heel-shin test; impaired balance in heel-toe walk and single-leg stance and/or hopping); or athetosis (ie, obvious athetoid or dystonic movements in the face, upper and/or lower limbs, trunk, or on one side of the body, or evident balance problems and incoordination during evaluation and the field of play).12

This sample was recruited from 11 national teams that took part in an international CP football competition. The inclusion criteria were a valid license for competing in this para-sport and a physical assessment report (ie, classification) that includes the type of impairment and sport class.

All of the participants had an international competition level background: 22.5% of the participants had competed in Paralympic games, 58.1% had previously competed in international-level tournaments and the rest of the participants (19.4%) participated for the first time in the competition where data collection took place. Additionally, 31 male football players without CP were also included in the study as a control group (CG). The inclusion criteria for the players in the CG were: not presenting any impairment or injuries, having similar levels of experience in football (ie, a minimum of 5 years of football competition), and a training workload (ie, a minimum of three training sessions per week) similar to that of para-footballers with CP. Control group players were recruited from two different football clubs located in the southern region of Spain. Approval by the principal investigator’s university review board was obtained before the study began (Ref. DPS. RRV.01.14).

Procedures

The team manager or national organization informed the para-athletes about this study before they arrived at the competition. All para-athletes who were eligible for inclusion in this study voluntarily agreed to participate and provided informed written consent before data collection. They were divided into groups of two to three participants and distributed across the testing stations. Therefore, the order of the two tests was counterbalanced across participants to reduce the bias caused by the order of the tests. Two trials were performed for each test and condition, and the best trial was used for the subsequent data analyses. All the tests and conditions were performed barefoot to avoid the interference of sports shoes and/or insoles/orthosis to move/keep the CoP within the BoS.13

| Impairment profile   | N   | Age (y)       | Body mass (kg) | Height (cm) | BMI (kg/m²) | Experience (y) | Training load (sessions/week) |
|----------------------|-----|---------------|----------------|-------------|-------------|----------------|-----------------------------|
| Spastic diplegia     | 11  | 25.6 ± 6.5    | 69.9 ± 8.4     | 175.4 ± 6.6 | 22.4 ± 2.3  | 9.9 ± 6.0      | 4.4 ± 1.2                  |
| Ataxia/athetosis     | 19  | 27.0 ± 8.0    | 68.9 ± 9.6     | 175.3 ± 7.3 | 22.5 ± 3.0  | 9.6 ± 4.3      | 3.0 ± 2.0                  |
| Spastic hemiplegia   | 81  | 25.2 ± 6.1    | 69.5 ± 8.6     | 175.5 ± 7.6 | 22.7 ± 2.9  | 9.9 ± 7.0      | 3.3 ± 1.7                  |
| Minimum impairment   | 18  | 28.4 ± 8.4    | 75.2 ± 9.4     | 176.9 ± 7.7 | 24.0 ± 2.3  | 16.0 ± 11.5    | 3.7 ± 1.9                  |
| Overall cerebral palsy | 129 | 25.9 ± 6.8   | 70.3 ± 9.0    | 175.7 ± 7.4 | 22.8 ± 2.8  | 10.7 ± 7.7     | 3.4 ± 1.8                  |
| Control group        | 31  | 19.5 ± 3.7    | 72.4 ± 7.2     | 178.7 ± 5.9 | 22.7 ± 1.8  | 9.3 ± 5.3      | 3.4 ± 0.5                  |

Abbreviation: BMI, body mass index
addition, both tests were performed with both arms across the chest (ie, the “guard arm” posture) to standardize the tests and control potential compensatory strategies to maintain balance. Each test was directly supervised and timed by the same member of the research team to increase the measurement for consistency.

**Dynamic balance: tandem walk test**

Participants were requested to walk barefoot in a straight line with the front foot placed such that its heel touched the toe of the standing foot. Two conditions were applied in the following order: (1) to complete 10 correct steps (TW10S) and (2) to complete a 5-m distance (TW5M). A trial was invalidated when a participant lost balance or placed a foot away from the straight line. Only one extra trial was allowed for intra-session reliability purposes (ie, two valid trials). There was a 1-minute rest between trials and 2 minutes of rest between conditions. A short period of time expended to accomplish the tests was considered to indicate better dynamic balance performance. The discriminant validity and reliability of both tests as a clinical measure of dynamic balance for people with CP have been proven previously.

**Static balance: one-leg stance test (OLS)**

The participant stood barefoot on a 60 × 40 cm force platform (Kistler, Switzerland, Model 9287B). Before raising one leg off the platform surface, participants crossed their arms across their chest. The stopwatch (Casio HS-3 V, Tokyo, Japan) was started as soon as the participant lifted a foot off the platform. The participants were asked to stand as still as possible while they focused on a spot on the wall at eye level. The ground reaction forces and the CoP displacements were recorded at 1000 Hz and calibrated at the beginning of each participant’s data collection. The test duration was set at 30 seconds. Two trials were performed with each leg, always starting with the dominant or less affected leg (OLS_D) and following with the non-dominant or more affected leg (OLS_ND). We considered the dominant leg to be the one showing less impairment by analyzing the following items: (1) the leg with the lowest level of spasticity for those with unilateral spasticity or hemiplegia and (2) the preferred leg for kicking and passing during the game for those with bilateral impairment. This information was collected before the evaluation, asking participants about their less affected and/or their preferred leg for passing and kicking during the game, respectively. There were 1-minute rest intervals between trials and 2 minutes of rest between legs.

**Data extraction**

A custom software program in LabVIEW (version 12.0, National Instruments, Austin, Texas, USA) was used for data analysis of the OLS outcomes. Because there is little physiological significance to CoP signal frequencies above 10 Hz, CoP was first filtered using a low-pass filter (fourth-order, zero-phase lag, Butterworth, 5 Hz cutoff frequency) according to Lin et al, and second, CoP time series were subsampled at 20 Hz. The first 5 seconds of each trial were discarded to avoid the signal nonstationarity related to the start of the measurement. Therefore, the last 25 seconds of each trial were used to calculate the CoP outcomes. The following variables were obtained for data analysis of static balance according to Prieto et al:

1. The SD of the CoP displacement in the mediolateral axis (DML, in mm);
2. The SD of the CoP displacement in the anteroposterior axis (DAP, in mm);
3. The resultant distance as a global measure to quantify the balance performance during trials, calculated as the average of the absolute CoP distance to the participant’s CoP midpoint (RD, in mm);
4. The mean velocity of the CoP, quantified as the path traveled by the CoP per second (MV, in mm/s).

**Statistical Analysis**

This study used a cross-sectional design, considering the testing conditions in the TW (ie, TW10S and TW5M) and the performance leg in the OLS tests (ie, OLS_D and OLS_ND) as within-participant factors, and the CP profiles and CG as a between-group factor (ie, spastic diplegia, ataxia/athetosis, spastic hemiplegia, minimum impairment, and nondisabled). A priori power analysis for sample estimators was done using G*Power (version 3.1.9.4). The effect size was set at 0.25 level and power was set at 0.95 level.

Descriptive statistics were calculated for the TW and OLS tests. Kolmogorov–Smirnov and Levene’s tests were applied to confirm the data normal distribution and the homogeneity of variances. Subsequently, statistical parametric techniques were carried out. The intraclass correlation coefficient (ICC) and the SEM were calculated to assess intra-session relative and absolute reliability, respectively. The ICC values were categorized as follows: excellent (0.90-1.00), high (0.70-0.89), moderate (0.50-0.69), and low (<0.50). SEM was calculated as the SD of the difference between two scores divided by square root of 2 and is expressed as a percentage (SEM%) by dividing its score by the mean. Confidence interval limits for ICC and SEM% were calculated at 90%. The relationships among the dynamic and static balance variables were assessed using Pearson’s product-moment correlation (r), and interpreted as follows: <0.1 trivial, 0.1 to 0.3 small, <0.3
to 0.5 moderate, <0.5 to 0.7 large, <0.7 to 0.9 very large, and <0.9 to 1.0 almost perfect. Reliability and correlational analyses were carried out in each group separately.

Mixed analyses of variance were carried out to test the conditions in the TW test (two levels: TW10S and TW5M) and the leg in the OLS test (two levels: dominant and nondominant) as within-participant factors and the group (five CP profiles, ie, spastic diplegia, ataxia/athetosis, spastic hemiplegia, minimum impairment, and nondisabled) as the between-participant factor. Tukey’s post-hoc tests were used for multiple comparisons between groups. Two effect size indexes were used to assess the practical signification of the within- and between-group differences. On one hand, partial eta-square ($\eta^2_p$) values were calculated as a measure of the effect size for mean differences in the analysis of variance (ANOVA), with the following interpretation: above 0.26, between 0.26 and 0.02, and lower than 0.02 were considered as large, medium, and small effects, respectively. On the other hand, to calculate the effect size of the post-hoc between-group differences, Cohen’s $d^{39}$ index was used with the following reference scores: above 0.8, between 0.79 and 0.50, between 0.49 and 0.20, and lower than 0.19 were considered as large, moderate, small, and trivial effects, respectively. All analyses were performed using the SPSS package (version 24, SPSS Inc., Chicago, IL, USA) with a significance level set at $P < .05$.

**RESULTS**

All participants included in this study completed the two trials in both balance tests, save one participant, who presented such a level of dyskinesia that he was unable to perform both tests properly. A priori power analysis reported a required sample of 142 for a critical $F$ value of 1.78, but the valid number of participants for data analysis was 139. The analyses conducted with the data collected reported power outputs ranged from 0.87 to 1.00, supporting appropriate statistical power.

**Test Reliability and Correlation Analysis**

Table 2 includes the relative (ICC) and absolute (SEM %) reliability scores for both dynamic (TW) and static (OLS) balance tests and according to those participants with and without CP. Overall, the non-CP participants had slightly better relative reliability scores (high-to-excellent: 0.81–0.98) than para-athletes (moderate-to-excellent: 0.60–0.95). Non-CP participants also showed better absolute reliability scores (CP: 10.5–64.4%, CG: 3.9–39.7%). Overall, TW tests showed better SEM scores than OLS in both groups.

| Table 2 Absolute and relative reliability of the balance measurements |
|--------------------------|--------------------------|--------------------------|
|                         | CP                        | CG                        |
|                         | ICC$_{1,2}$ | SEM% | ICC$_{1,2}$ | SEM% |
| Dynamic balance         |                      |                          |                      |
| TW$_{10S}$              | 0.85 | 16.7 | 0.94 | 3.9 |
| TW$_{5M}$               | 0.95 | 10.5 | 0.81 | 7.4 |
| OLS dominant            |                      |                          |                      |
| DML                     | 0.68 | 36.3 | 0.91 | 21.7 |
| DAP                     | 0.68 | 64.4 | 0.80 | 39.7 |
| RD                      | 0.62 | 60.2 | 0.92 | 22.6 |
| MV                      | 0.81 | 25.6 | 0.98 | 12.4 |
| OLS nondominant         |                      |                          |                      |
| DML                     | 0.60 | 34.5 | 0.88 | 22.5 |
| DAP                     | 0.77 | 36.9 | 0.95 | 18.8 |
| RD                      | 0.81 | 30.0 | 0.84 | 30.8 |
| MV                      | 0.88 | 23.1 | 0.97 | 16.9 |

Abbreviations: CG, control group; CP, cerebral palsy; ICC, intraclass coefficient; DAP, standard deviation of the center of pressure displacement in the anteroposterior axis; DML, standard deviation of the center of pressure displacement in the mediolateral axis; MV, center of pressure’s mean velocity; OLS, one-leg stance test; RD, average of absolute center of pressure distance to the participant’s midpoint; TW$_{5M}$, tandem walk 5 m; TW$_{10S}$, tandem walk 10 steps.

| Table 3 Bivariate correlations between TW and OLS |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
|                         | DML | DAP | RD | MV |
| Dominant side           |                      |                          |                          |                      |
| TW$_{10S}$              | CP  | 0.28‡ | 0.30‡ | 0.29‡ | 0.30‡ |
|                         | CG  | 0.02 | 0.05 | 0.03 | 0.03 |
| TW$_{5M}$               | CP  | 0.23‡ | 0.26‡ | 0.26‡ | 0.26‡ |
|                         | CG  | -0.02 | 0.02 | 0.01 | 0.01 |
| Nondominant side        |                      |                          |                          |                      |
| TW$_{10S}$              | CP  | 0.03 | 0.17 | 0.15 | 0.15 |
|                         | CG  | 0.06 | 0.06 | 0.06 | 0.05 |
| TW$_{5M}$               | CP  | 0.07 | 0.15 | 0.17 | 0.15 |
|                         | CG  | -0.01 | 0.01 | -0.01 | 0.04 |

Abbreviations: CG, control group; CP, cerebral palsy; DAP, standard deviation of the center of pressure displacement in the anteroposterior axis; DML, standard deviation of the center of pressure displacement in the mediolateral axis; MV, center of pressure’s mean velocity; OLS, one-leg stance test; RD, average of absolute center of pressure distance to the participant’s midpoint; TW$_{5M}$, tandem walk 5 m; TW$_{10S}$, tandem walk 10 steps. ‡$P < .01$.

The bivariate correlation analyses revealed a large correlation between the two conditions of the TW test ($r = 0.83$, $P < .01$) for the CP group, whereas the same correlation was moderate in the CG ($r = 0.66$, $P < .01$). Table 3 shows the correlation between the dynamic test and the static balance test performed with the dominant or less affected and the nondominant or more affected legs. Small to moderate correlations ($r = 0.23–0.30$, $P < .01$)
were found only for the CP group when performing the OLS test with the dominant or less affected leg.

**Between-group comparisons**

Table 4 shows the overall differences between the CP and the control groups, observing significant differences for the dynamic balance tests and the static balance test performed with the nondominant leg. The mixed-ANOVA analysis for the tandem-walk test revealed significant within-participant differences between the two tandem walk conditions \([F(1,155) = 206.3; P < .01; \eta^2 = 0.59, \text{large}]\), significant between-group differences \([F(4,155) = 14.4; P < .01; \eta^2 = 0.29, \text{large}]\), and a significant interaction effect \([F(4,155) = 5.0; P < .01; \eta^2 = 0.12, \text{medium}]\). Specifically, Figure 1 shows the differences between CG and the four CP profiles and their overall score in both TW tests \((P < .01)\). When comparing the four CP profiles, we only found significant differences in the TW10S between the ataxia/athetoid group and the spastic hemiplegia group \((P < .05; d = 0.55, \text{moderate})\) and the minimum impairment \((P < .05; d = 0.64, \text{moderate})\) profile.

The second mixed-ANOVA analysis also revealed significant differences between the two OLS conditions (ie, dominant/less affected vs nondominant/more affected legs) in the four variables calculated \([F(1,155) = 11.6–16.0; P < .01; \eta^2 = 0.07–0.10, \text{medium}]\). Also, there were interaction effects for the DML, DAP, RD, and MV outcomes \([F(4,155) = 4.9–7.7; P < .01; \eta^2 = 0.12–0.17, \text{medium}]\). The ANOVA model also revealed significant between-group differences for the four static balance outcomes \([F(4,155) = 4.8–10.7; P < .01; \eta^2 = 0.12–0.23, \text{medium}]\). Most of the significant differences for the between-group comparisons occurred between the ataxic/athetoid CP profile and the rest of the profiles and CG, and most commonly in the OLS\(D\) \((14/16, d = 0.54–3.67)\) than in the OLS\(ND\) \((7/16, d = 0.70–1.24)\) (Table 5). The other CP profile with several differences was the spastic hemiplegia group when performing the OLS\(ND\) and compared with the CG in DML \((P < .05; d = 0.50, \text{moderate})\), DAP \((P < .01; d = 0.77, \text{moderate})\), RD \((P < .01; d = 0.80, \text{large})\), and MV \((P < .01; d = 0.91, \text{large})\).

**TABLE 4** Mean and SDs of the balance measurements and between-group overall comparison

|                      | CP (M ± SD) | CG (M ± SD) | \(P\)  | \(d\) |
|----------------------|-------------|-------------|--------|-------|
| **Dynamic balance**  |             |             |        |       |
| TW\(_{10S}\) (s)     | 9.18 ± 3.84 | 4.12 ± 0.75 | <.001  | 1.45  |
| TW\(_{5M}\) (s)      | 16.24 ± 7.31| 7.56 ± 1.21 | <.001  | 1.31  |
| **OLS dominant**     |             |             |        |       |
| DML (mm)             | 0.99 ± 0.63 | 0.88 ± 0.89 | .446   | 0.16  |
| DAP (mm)             | 1.16 ± 1.28 | 0.67 ± 0.82 | .043   | 0.41  |
| RD (mm)              | 1.27 ± 0.93 | 0.97 ± 1.03 | .126   | 0.32  |
| MV (mm/s)            | 6.09 ± 3.99 | 4.81 ± 6.25 | .158   | 0.28  |
| **OLS nondominant**  |             |             |        |       |
| DML (mm)             | 1.71 ± 1.87 | 0.76 ± 0.60 | .006   | 0.56  |
| DAP (mm)             | 2.52 ± 2.65 | 0.61 ± 0.62 | <.001  | 0.80  |
| RD (mm)              | 2.24 ± 1.98 | 0.86 ± 0.74 | <.001  | 0.76  |
| MV (mm/s)            | 9.63 ± 6.70 | 4.36 ± 5.88 | <.001  | 0.80  |

Abbreviations: CG, control group; CP, cerebral palsy; \(d\), Cohen’s effect size; DAP, SD of the center of pressure displacement in the anteroposterior axis; DML, SD of the center of pressure displacement in the mediolateral axis; M, mean; MV, center of pressure’s mean velocity; OLS, one-leg stance test; RD, average of absolute center of pressure distance to the participant’s midpoint; TW\(_{5M}\), tandem walk 5 m; TW\(_{10S}\), tandem walk 10 steps.

**FIGURE 1** Performance in the two tandem walk conditions. Abbreviations: TW\(_{10S}\), tandem walk 10 steps; TW\(_{5M}\), tandem walk 5 m.
Balance is a relevant body function for ambulant individuals with CP. The assessment of balance in children and young people with CP is widely used in clinical settings for rehabilitation purposes, but data on balance in adults with CP are scarce. For example, as higher levels of muscle strength can improve balance in people with CP, using data obtained from children in adult studies is not suitable; adults’ strength tends to be greater because of maturity, so their levels of balance would also be better. Some studies on young adults with CP concluded that effective therapy to improve walking might incorporate balance-focused exercises, like those related to the Berg’s Balance Scale (BBS) items, which are strongly associated with mechanical efficiency. The tests used in this study to assess dynamic and static balance are similar to those used in items 13 and 14 of BBS. This tool has been considered useful to evaluate, discriminate, and predict balance performance in people with CP. Those items are strongly related to mechanical efficiency, dynamic balance, and gait ability. Nevertheless, the reliability and the strength of the associations between these balance measurements have not been previously explored in ambulant para-athletes with CP (ie, Level I of the GMFCS), nor have different CP profiles been compared.

The overall comparison between the CP and control groups demonstrated that balance function is impaired in ambulant, well-trained, Level I GMFCS para-athletes with CP. To the best of the authors’ knowledge, only a study by Lopes and David compared a sample similar to that included in this study. They compared a sample of 14 para-footballers with CP and 14 individuals without neurological impairments when performing bipedal and single-leg stance tests on a force platform, demonstrating that those without impairment showed better performance in the single-leg test for CoP medial-lateral, anterior-posterior and ellipse/area displacements but not for CoP velocity, as our study found. The study by Lopes and David also compared the whole CP sample with a control group, but those results may be biased by the different CP profiles included in the sample that were considered as a single group.

Test reliability and correlation analysis

Regarding test reliability, to the best of the authors’ knowledge, there is no previous research using the tests included in this study with well-trained adults with CP. A study analyzing one-leg standing and walking on a line in children with CP and a nondisabled group demonstrated moderate-to-good intersession reliability (ICC = 0.50–0.99), suggesting that these tests can be used to monitor balance control in children without disability; however, only the one-leg standing test was reliable in children with CP. A modified version of the BBS applied at a pediatric stage also demonstrated good test-retest and interrater reliability when it was used with school-age children with mild to moderate motor impairment. However, they found that reliability scores were better for tandem versus the one-leg standing tests, similar to what our study found in adult para-athletes. A recent study by Zarkou et al provided preliminary evidence that lower limb sensory deficits can contribute to the pronounced lack of balance and motor impairments in people with CP. This may explain the increased difficulty of performing a balance test with one leg, which would present higher performance variability in people with CP (ie, lower ICC and higher SEM % when comparing CP vs CG and TW vs OLS). Despite this difference, the MV of the CoP speed was the most reliable CoP parameter in both groups and OLS conditions. In this line, a recent study by Reina et al demonstrated that the magnitude of the mean velocity in the one-legged stance test is one of the

| Leg          | Subgroup          | DML | DAP | RD   | MV   |
|--------------|-------------------|-----|-----|------|------|
| Dominant     | Diplegia          | 2.07| 3.22| 3.48 | 3.67 |
|              | Hemiplegia        | 0.62| 0.71| 0.66 | 0.82 |
|              | Minimal impairment| 0.20| 0.56| 0.37 | 0.54 |
|              | Control group     | 0.57| 0.79| 0.70 | 0.86 |
| Nondominant  | Diplegia          | 0.32| 0.55| 0.47 | 1.24 |
|              | Hemiplegia        | 0.13| 0.28| 0.40 | 0.33 |
|              | Minimal impairment| 0.82| 0.74| 0.70 | 0.77 |
|              | Control group     | 1.00| 0.92| 0.89 | 0.96 |

Abbreviations: DAP, SD of the center of pressure displacement in the anteroposterior axis; DML, SD of the center of pressure displacement in the mediolateral axis; MV, center of pressure’s mean velocity; OLS, one-leg stance test; RD, average of absolute center of pressure distance to the participant’s midpoint.

†P < .05, †P < .01.
three most sensitive variables to cluster lower limb performance in para-athletes with spastic hemiplegia, the group with the highest prevalence in our study. Therefore, it is plausible to think that this variable may reflect the fine-tune adjustments performed by the participant to keep a stable, upright position and optimize their postural control.\(^4\) From a clinical point of view, stability is expected to be better in patients who have lower CoP sway velocities,\(^4\) so this metric in static balance performance could be more useful compared to other measures of CoP displacement (ie, medial-lateral and anterior-posterior). Finally, it must be pointed out that, the high ICC scores indicated that both TW and OLS tests have a high ability to rank CP and non-CP individuals according to their balance performance, which is an important criterion of tests that serve classification purposes. However, SEM scores were high mainly in the CP group. The aforementioned higher variability performance shown by this group would hinder the identification of subtle changes in balance performance in longitudinal or experimental studies. In this sense, the better SEM scores obtained in the TW tests indicated that they are better tools than the OLS test to monitor balance changes along time. As a research implication, the absolute reliability of the balance test used in this study should be improved (eg, by increasing the number of trials performed during testing, averaging trials, etc.) if future studies choose to use them to track the effectiveness of any balance training programs in high functioning CP adults.

Regarding the relationship between static and dynamic balance, we found only small to moderate correlations (0.23–0.30) when people with CP performed both tests with the dominant side. This finding would be explained by the weight-bearing responses to keep balance and the overrepresentation of those with spastic hemiplegia in our sample (62.8%). A study by Domagalska-Szopa et al\(^5\) on children with unilateral spasticity revealed that their balance difficulties in keeping a standing position were caused by their tendency to load the affected lower limbs excessively or insufficiently. Therefore, it is plausible to think that, when performing TW, individuals with spastic hemiplegia tend to bear their weight on the nonaffected leg, leading to the positive correlations between TW and OLS\(_D\) variables. However, those with spastic diplegia and athetosis/ataxia might not be able to use that strategy to keep balance during TW. Nevertheless, the lack of correlations for the CG and the performance with the nondominant leg in both groups may also suggest that both tests evaluate different balance dimensions.

**Within- and between-group comparisons**

When comparing the two TW conditions, we found significant within-participant differences, with more time invested in performing the 5 m versus the 10 steps conditions, but this was not a relevant finding because more steps were required to cover the distance in TW\(_{5M}\). However, both TW conditions are sensible to reveal differences between well-trained participants with and without CP. According to the Newell’s constraints model,\(^5\) there is an interaction between the individual (ie, para-athlete) and the environmental (ie, task features) constraints. Using two different conditions of the same task would provide insightful information about the individual, task, and environment interactions,\(^5\) so it is plausible that individuals with different CP profiles would perform the balance tasks differently (eg, by using compensatory strategies). Hence, the TW\(_{5M}\) is more environmentally constrained (ie, completing the 5 m line by tandem walking as fast as possible), whereas the TW\(_{10S}\) is more individually constrained (ie, self-paced performance until completing the five steps required as fast as possible). The differences between CP profiles found in the TW\(_{10S}\) condition would be explained by the clear instructions provided about the “performance of 10 correct steps”; that is, this condition is sensitive to assessing balance activity limitations. However, the higher SDs found for each CP profile in the TW\(_{5M}\) may explain the lack of between-group differences. A study carried out with 48 para-footballers with CP also used the TW\(_{5M}\) and they did not find between-group differences when comparing the lower sport classes (ie, FT5: moderate spastic diplegia and FT6: moderate athetosis/ataxia) with the FT7 sport class (ie, moderate spastic diplegia) versus the minimum impairment sport class (ie, FT8). Nevertheless, the high effect sizes found between FT7 versus FT8 would support the aforementioned weight-bearing strategy when performing TW.

Regarding the two OLS conditions, the lack of differences between the CP and the control groups in the dominant test would be explained by the overrepresentation of participants with spastic hemiplegia. On the other hand, the performance differences when both the dominant and nondominant legs were compared are in line with previous studies conducted on para-athletes with CP.\(^4\) The study carried out by Reina et al\(^5\) demonstrated no differences between FT7 and FT8 sport classes in the OLS\(_D\), but significant differences in the OLS\(_{ND}\). Besides, the same study found significant differences between FT5/FT6 versus the FT7 sport classes in the OLS\(_D\) but not when comparing their performance with the nondominant leg (ie, OLS\(_{ND}\)). Again, the overrepresentation of para-athletes with spastic hemiplegia can explain this result, demonstrating that both static and dynamic postural stability parameters are affected in hemiplegic CP.\(^4\)

This study has some limitations and further research could be considered. First, there is an...
overrepresentation of para-athletes with spastic hemiplegia, but this is because of the predominance of para-athletes from the FT7 sport class and the higher prevalence of this profile among people with CP. Second, future studies would also explore the between-sessions test-retest reliability given that this study explores within-session reliability. Third, although the participants of the control group of this study are a bit younger compared to the para-athletes with CP, the authors aimed to recruit nondisabled footballers whose demographics of age, training load, and football experience/history are as similar as possible. Fourth, in this study, people with ataxia and athetosis were combined in a single group because of the prevalence of these impairments in the recruited sample, and they are combined for classification purposes in CP football and other Paralympic sports such as Para-athletics. Although both impairments comprise less than 15% of the general CP population, a recent study with international CP footballers suggests that the relationships between eligible impairment and activity limitation would be impairment specific. Hence, future research should evaluate static and dynamic balance, distinguishing between ataxic and dyskinetic CP profiles, to obtain a better understanding of their body function, postural control, and/or compensatory strategies.

CONCLUSION

Balance is a fundamental skill needed to carry out daily activities, including physical activities. The comparison with an able-bodied group showed that even the most functional (ie, Level I GMFCS) and well-trained CP profiles present altered balance, that is, more difficulties in keeping an upright weight-bearing position. Reliability scores were better for tandem versus the one-leg standing tests, and the small correlations found between static and dynamic balance measurements suggest different balance dimension where impairment would affect differently. Both conditions used in the TW test (ie, individual vs. environment constrained) are feasible options to discriminate balance performance between individuals with and without CP. Concerning the static balance, the CoP’s displacement in the anterior-posterior axis seems the variable best suited to discriminate between individuals with and without CP for both dominant and nondominant legs (ie, foot placement due to distal spasticity in legs or the presence of plantar-flexion contractures). Additionally, within CP functional profiles, data highlighted that balance performance is constrained to a higher extent in those individuals with ataxia or athetosis, with their involuntary, uncontrolled, recurring, and occasionally stereotyped movements, where primitive reflex patterns and muscle tone variations predominate.5

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The authors declare that they have no disclosures concerning this article.

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