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# Analysis of dynamic balance in preschool children through the balance beam test: A cross-sectional study providing reference values

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A R T I C L E  I N F O

*Keywords:*
Paediatrics
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A B S T R A C T

*Background:* dynamic balance (DB) is a complex ability at an early age and balance deficits are related to numerous disorders. There are several balance measures but wide variation in their use has restricted the capacity to synthesise references values. The main purpose of this study was to analyse the performance of the Balance beam test (BBT) in preschool children, according to age and sex providing BBT reference values, and also to analyse its reliability and validity.
Research question: could the BBT be a reliable test for measuring dynamic balance in preschool children?
*Methods:* 593 preschool children (3–6 years) participated in this study. The BBT was used to evaluate DB by measuring distance reached, time spent, and number of steps. Differences between sex and age groups were analysed using the Mann–Whitney U and Kruskal–Wallis tests. Test-retest reliability analysis was performed using intraclass correlation coefficients and the Bland–Altman graphic. Convergent validity was investigated with the Stork Balance stand test (SBST).
*Results:* no significant differences were found for sex in any components of the BBT. Age had positive effects on BBT performance in distance ($\chi^2 = 63.474$, $p < 0.001$), time ($\chi^2 = 46.441$, $p < 0.001$), and step numbers ($\chi^2 = 40.967$, $p < 0.001$). Younger children performed more poorly than older children. No significant interactions between age groups and sex were found. The BBT showed adequate validity and reliability.
*Significance:* the reference values established for Spanish preschool children in the current study could be used to monitor DB development. It is necessary to take into account distance reached, time spent, and the steps taken to obtain a more precise measure of DB in this population.

## 1. Introduction

The early years of life are a very rapid stage of development, marked by considerable growth and change in a child's motor repertoire [1]. Motor competence during infancy and childhood is influenced by the child's individual growth and morphological, physiological, and neuromuscular characteristics [2]. The mastery of fundamental motor skills (FMS) contributes to children's physical, cognitive, and social development and is essential for an active lifestyle and athletic participation in childhood and adolescence [3]. FMS are divided into three constructs: locomotive, object control, and stability skills [4]. In particular, balance control is an integral component of functioning, which is composed of the posture control (e.g. maintaining a posture) and the control of equilibrium (e.g. the control of destabilising forces acting on the body); the combination of both ensures the stability of the body during the use of several motor skills [5].Balance ability includes both static balance (SB) and dynamic balance (DB). The control of SB is defined as the ability to maintain the centre of gravity within the limits

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of the base of support [6], while DB can be defined as the ability to maintain stability while anticipating and reacting to changes as the body moves through space [7]. DB is essential in the development of locomotion [8], and in this regard, the initiation of gait involves a transient phase while moving from an initial standing posture into gait [9]. However, maintaining balance during locomotion is a complex ability that combines forward propulsion of the body, lateral stability, and holding the body on one leg during the swing phase of the gait [10]. In this regard, balance deficits have been well-demonstrated in children with several disorders, including autism [11], Down's syndrome [12], and developmental coordination disorders [13].

Balance control can be analysed by the Systems framework that describes six components required for the maintenance of posture: (1) constraints on the biomechanical system, (2) movement strategies, (3) sensory strategies, (4) orientation in space, (5) dynamic control, and (6) cognitive processing. Each element and type of control can independently lead to a balance deficiency [14].This framework highlights the need for individual assessment of each component [14].

The conceptual framework for testing DB in children includes several procedure and field-based tests, such as: unilateral DB tests (Y balance test) [7], beam walking tasks [15] and the timed up and go [16].These types of tests are particularly important for assessing children in more traditional and accessible community venues such as schools. Therefore, we might assume that the balance beam test (BBT) it is more challenging than e.g. the timed up and go, and thus perhaps more sensitive for very mild balance problems, or on the other hand sensitive to select children with better than average balance performance

However, despite the fact that there are several balance measures, wide variation in their use has restricted the capacity to synthesise data on the effects of balance training programmes [14]. In addition, because of a lack of good methodological studies, strong evidence for the use of one or more functional balance measures in children cannot be provided [5]. Therefore, it is necessary that a standard criterion to measure balance is established and that structural validity and responsiveness of the existing tests are further evaluated [5].

Few studies have examined DB in healthy preschool children using field-based assessments [17–19], showing that the DB is influenced by age but not by sex or anthropometric variables such as body mass index (BMI). To the best of the authors' knowledge, no information is available to date regarding reference values for the BBT in preschool children, and the reliability of the performance variables in this test such as the distance travelled, time spent, or the steps taken has not been established. Therefore, the main purpose of this study was to analyse the BBT performance according to age, sex, and anthropometric characteristics in Spanish preschool children, as well as to provide BBT reference values for this group. A second objective was to analyse the reliability and validity of the BBT. We hypothesised that there are no significant differences in BBT performance between children of different sexes, however, age may have an influence on BBT performance.

## 2. Methods

### 2.1. Participants

A total of 593 children, selected from 12 schools in southern Spain, participated in this study (age = 4.31 ± 0.99 years; age range = three to six years, BMI = 15.65 ± 2.62 kg/m$^2$; 303 girls and 290 boys). The sample was selected from a large region of Andalusia (Spain) containing both urban and rural populations. Inclusion criteria for participant selection were early childhood school enrolment and the absence of any neurodevelopmental or neuromotor disability, such as autism, Down's syndrome, and/or the presence of any pathological disorder associated with the visual or vestibular systems. Inclusion and exclusion criteria were evaluated based upon a parental questionnaire, and in addition, parents voluntarily signed an informed consent form permitting their children to participate in this study. The study was completed per the norms of the Declaration of Helsinki (2013 version). The study was approved by the Ethics Committee at the University of Jaen (Spain).

### 2.2. Materials and testing

Body height (cm) was measured with a stadiometer (Seca 222, Hamburg, Germany) and weight (kg) with a standard weight scale (Seca 899, Hamburg, Germany).

DB was determined using the BBT. The BBT is a simple test of DB in which the subject walks on a 4 cm wide by 12 cm tall 2.5 m-long wooden balance beam (Picture 1) [15,16]. The balance beam is held by two 40 × 30 cm platforms. Because there is a relationship between SB and DB in preschool children [20], convergent validity was investigated with the stork balance stand test(SBST) [21], both right and left foot data were collected, and the average was used for analysis.

### 2.3. Procedure

The following standardised testing procedure was used for the BBT: the participant stood without shoes on the starting platform and, when signalled, walked forward on the balance beam using a heel-to-toe pattern; the subject could keep their eyes open and move their arms freely. The trial ended when the participant arrived at the opposite platform. If a child fell midway on the beam they were asked to stand back on the beam and continue from where they fell. The test was timed (s) using a stopwatch. As an additional outcome measure, the number of consecutive steps successfully taken on the beam until the child's foot touched the floor or they reached the opposite platform were counted and the distance achieved was registered. Two attempts were made, and the best result was used for analyses. The test score included the run-time, steps performed, and distance achieved; a longer time indicated poorer performance, while a greater number of steps or distance indicated better performance. The research team conducted a demonstration

**Picture 1.** Balance beam test.

for the participant prior to testing and the children also performed some familiarisation trials with the BBT, making between two and three attempts. The children were encouraged to achieve the best score possible (by walking as fast as possible from one platform to the other without falling). The measurement was repeated if a child repeatedly fell off the beam and was unable to climb back onto it; a subject was judged unmeasurable if this scenario occurred three times in succession. One week after initial testing, 72 children (included in the previous data collection) performed the same test (re-test).

The following standardised testing procedure for the SBST was used: participants stood without shoes on one foot and placed their hands on their hips with their opposite foot placed against the inside of the supporting knee. On a signal, the subject raised the heel of their foot from the floor and attempted to maintain their balance for as long as possible, up to one minute. The trial ended if the subject either moved their hands from their hips, the supporting foot moved from its original position, or the non-supporting foot lost contact with the knee. The test was timed (s) using a stopwatch that was started when the heel was raised from the floor and recorded for up to one minute. Two attempts were made per leg; right and left foot data were both collected, and the best result (s) was scored for each, after which the average was used. The test score was the runtime, with a longer time indicating a better performance.

### 2.4. Statistical analysis

Data were analysed using SPSS, v.19.0 for Windows (SPSS Inc, Chicago, USA), statistical software package R (R Core Team, 2016) with the GAMLSS package and MedCalc Software (Mariakerke, Belgium). The significance level was set at $\alpha < 0.05$. The data are shown in descriptive statistics for means, standard deviations, and percentiles. Tests of normal distribution and homogeneity (Kolmogorov–Smirnov and Levene's test, respectively) were conducted on all data before analysis. Differences between sex and age groups were analysed using Mann–Whitney U and Kruskal–Wallis tests respectively with Bonferroni correction. A partial correlation analysis was performed between the BBT and various sex and age-adjusted anthropometric variables. Test-retest reliability analysis was performed using intraclass correlation coefficients (ICC, absolute-agreement, 2-way mixed-effects model) and the Bland–Altman graphic, a method to quantify agreement between two quantitative measurements by constructing limits of agreement. These statistical limits are calculated by using the mean and the standard deviation of the differences between two measurements. Coefficient of variation (CV, %) and standard error of measurement (SEM) were calculated as a measure of absolute reliability. Convergent validity was investigated with a Spearman correlation between BBT and SBST. For the distance travelled, time spent, or the steps taken in the BBT, the percentile curves were calculated as a function of age-stratified by sex using several methods for developing age-related curves have been developed. The Lambda, Mu and Sigma method (LMS) offer an approach to model data with consideration of $\mu$ as location parameter (median) as well as $\sigma$ as scale parameter (coefficient of variation) and the skewness parameter $\lambda$ as shape parameter. This method was implemented in the GAMLSS package in R software. For the analysis of heteroscedasticity, mean differences in relation to the individual values were computed and we calculated the correlation coefficient [22].

## 3. Results

### 3.1. Age and sex differences

Table 1 shows performance on the BBT with regard to sex and age. No significant differences were found for sex in terms of distance, time, or number of steps reached on the BBT. In contrast, we found that age had positive effects on BBT performance in terms of distance ($\chi^2 = 63.474$, $p < 0.001$), time ($\chi^2 = 46.441$, $p < 0.001$), and number of consecutive steps ($\chi^2 = 40.967$, $p < 0.001$) in the sample total, and in boys: distance ($\chi^2 = 34.908$, $p < 0.001$), time ($\chi^2 = 23.003$, $p < 0.001$), and number of consecutive steps ($\chi^2 = 19.369$, $p < 0.001$), and in girls: distance ($\chi^2 = 28.563$, $p < 0.001$), time ($\chi^2 = 24.218$, $p < 0.001$), and number of consecutive steps ($\chi^2 = 21.598$, $p < 0.001$). Overall, post-hoc analysis revealed that the younger children achieved a shorter distance, fewer numbers of steps, and spent more time, compared with the older children. Interactions between age-groups and sex with performance on the BBT are shown in Fig. 1. No significant differences were found in any variable.

With regard to anthropometric parameters, body height and body mass both showed significant correlations with BBT performance, specifically: body height with distance ($r = -0.273$, $p < 0.001$), and number of steps ($r = -0.243$, $p < 0.001$); and body weight with time ($r = -0.116$, $p = 0.008$). However, no correlation was found between performance on the BBT and a child's BMI. Normative values for BBT performance in Spanish preschool children according to sex and age are shown in Fig. 2 and are expressed in percentiles.

### 3.2. Reliability and convergent validity

Table 2 shows the descriptive statistics in test and retest and variables of reliability. It is noteworthy that SEM is higher in the distance reached than in the number of step or in the time spent.

For distance reached, the Bland–Altman graphic showed limits of agreement (2 SD) of 121.9 cm and −133.8 cm and a mean of the differences equal to −6.0 cm. Concerning time registered, the limits of agreement were 13.0 s and −15.80 s while the mean of the differences was −1.4 s. For steps performed, the limits of agreement were 4.41 steps and −4.58 steps, and the mean of the differences was equal to −0.1 steps.

Regarding convergent validity between the BBT and SBST, Spearman correlation coefficients of $r = 0.346$, $p = 0.001$, $r = -0.256$, $p = 0.015$, and $r = 0.339$, $p = 0.001$ were obtained for distance, time, and number of steps, respectively. Additionally, Spearman correlation analysis showed significant correlations between distance, time, and number of steps with age, corresponding to $r = 0.322$, $p < 0.001$, $r = -0.280$, $p < 0.001$, and $r = 0.240$, $p < 0.001$, respectively. Finally, significant correlations between distance with time ($r = -0.427$, $p < 0.001$), distance with steps ($r = 0.816$, $p < 0.001$), and time with steps ($r = -0.355$, $p < 0.001$) were found Fig. 3.

**Table 1**
Balance beam performance according to sex and age. The data are shown as a mean (SD).

| | All (n = 593) | Boys (n = 290) | Girls (n = 303) | p-value | 3 years n = 152 | 4 years n = 175 | 5 years n = 191 | 6 years n = 75 | $\chi^2$ | p-value | Post-hoc analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance reached (cm) | 67.92 (62.70) | 67.57 (64.47) | 68.28 (60.94) | 0.625 | 41.50 (35.30) | 62.93 (58.18) | 73.48 (62.67) | 108.00 (82.67) | 32.063 | <0.001 | 3 < 4*, 3 < 5,6 ***, 4 < 6***, 5 < 6** |
| Number of steps | 4.00 (2.91) | 3.95 (2.87) | 4.05 (2.95) | 0.667 | 2.80 (1.84) | 4.03 (2.97) | 4.18 (2.94) | 5.47 (3.39) | 30.341 | <0.001 | 3 < 4, **, 3 < 5,6***, 4 < 6**, 5 < 6** |
| Time used (s) | 16.96 (7.90) | 16.76 (7.83) | 17.17 (7.98) | 0.648 | 19.51 (8.39) | 18.19 (8.34) | 15.78 (7.41) | 13.30 (5.03) | 23.917 | <0.001 | 3>, 5,6***, 4 > 5*,4 > 6***,5 > 6* |

*p < 0.05, ** p < 0.01, ***p < 0.001.

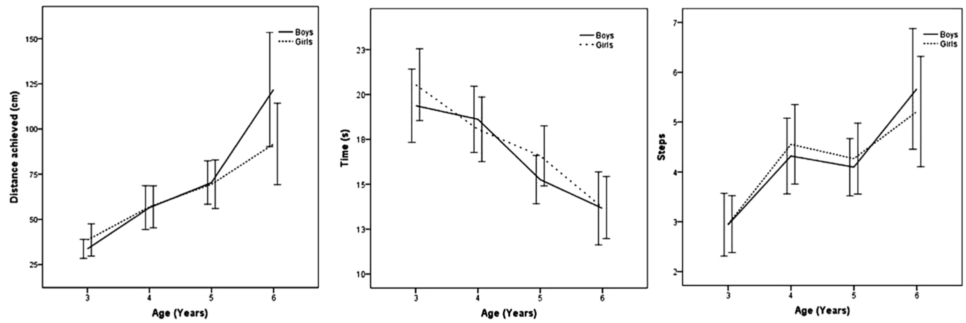


**Fig. 1.** Age-group and sex differences in balance beam test performance. The data are shown as a mean (SD).

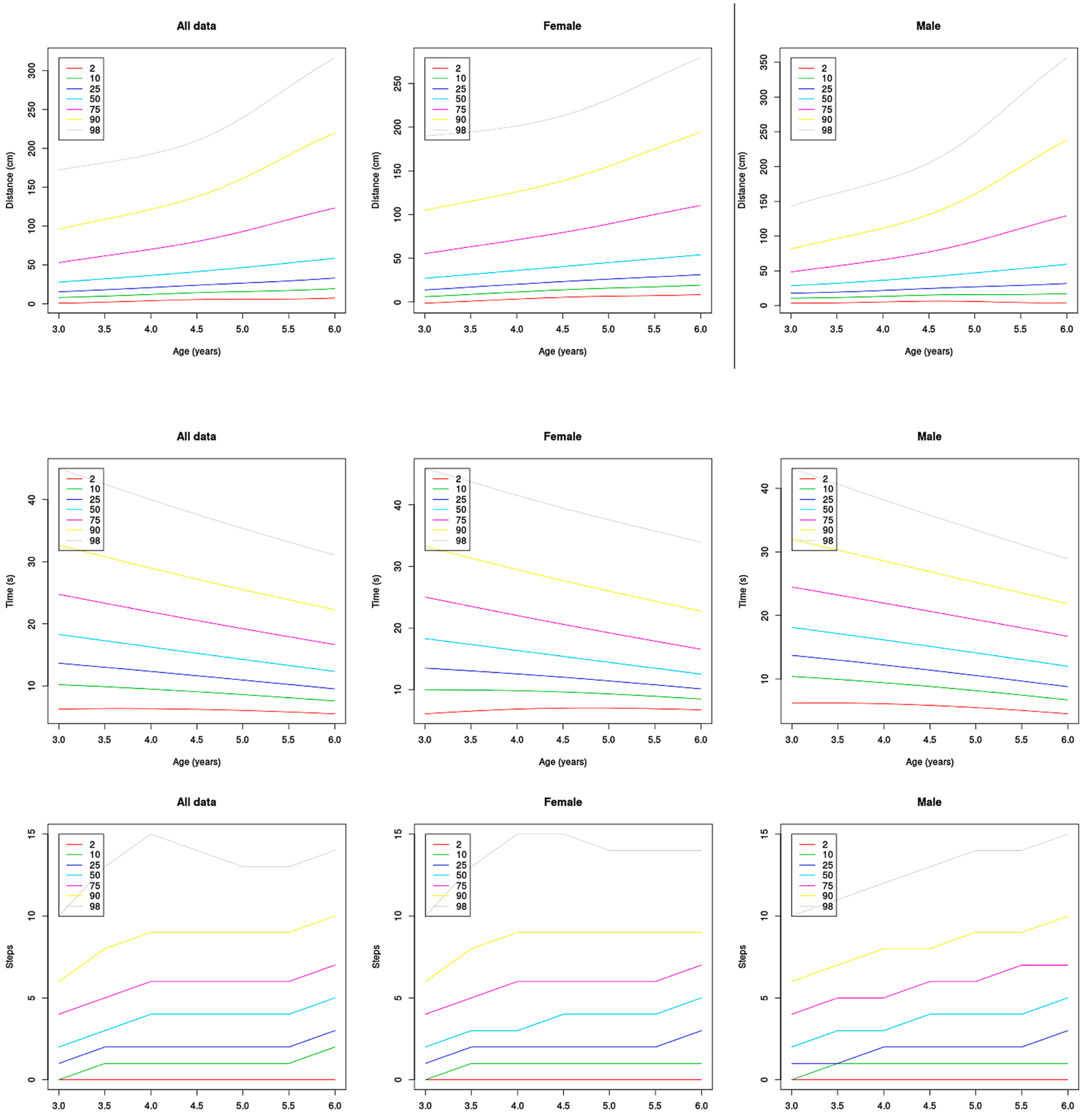


**Fig. 2.** Percentile curves for balance beam test (Distance reached, in cm, time used, in second and number of steps) for the total sample, boys and girls, from percentile 2 to percentile 98.

**Table 2**
Descriptive statistics in pretest and retest and variables of reliability.

| | Pre-test Mean (SD) | Re-test Mean (SD) | p-value | R | $R^2$ | ICC | 95 % confidence interval | SEM | SEM (%) | CV (%) | Heteroscedasticity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance reached (cm) | 80.16 (70.49) | 74.19 (75.55) | 0.061 | 0.588*** | 0.364 | 0.751*** | 0.602–0.844 | 0.35 | 45 | 59.59 | 0.087 |
| Number of steps | 4.06 (2.68) | 3.97 (2.69) | 0.377 | 0.664*** | 0.409 | 0.780*** | 0.649–0.863 | 1.25 | 31 | 40.58 | 0.003 |
| Time spent (s) | 16.45 (8.88) | 15.05 (7.51) | 0.108 | 0.663*** | 0.374 | 0.753*** | 0.605–0.845 | 4.01 | 25 | 33.5# | −0,208 |

*** $p < 0.001$. Intraclass correlation coefficients (ICC). Standard error of measurements (SEM). Coefficient of variation (CV). #Logarithmic method.

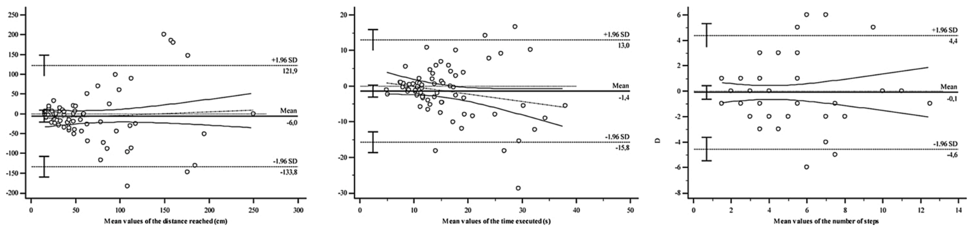


**Fig. 3.** Bland-Altman graphs of Balance beam test; the x-axis shows mean values of balance beam test and the y-axis the difference values of post-test-re-test of balance beam test for distance, time and step performed.

## 4. Discussion

The main purpose of this study was to analyse BBT performance according to age, sex, and anthropometric characteristics in Spanish preschool children, as well as to provide BBT reference values for this group. As hypothesised, there were no significant differences in average overall BBT scores according to sex. There were also no significant interactions between the sex and age of the children. These results are hardly comparable with other studies due to the different methodologies used for the assessment of DB. However, our findings do align with previous studies that have demonstrated no significant sex differences in regards to balance beam walking in preschoolers [15,23]. However, other studies have found that girls perform better than boys on balance tests [24]. Therefore, our research adds to the ongoing discussion regarding differences in balance among preschool children associated with their sex.

Regarding age, the results of the current study provide further support for the hypothesis that balance control improves as a result of maturation [25]. In the current study, younger preschool children displayed worse performance in all parameters of the BBT compared to older children. Several possible explanations exist for these results. Since younger children do not demonstrate integrative postural adjustments, which keep the pelvis from dropping to the side of the swing leg during foot lift-off [26], it seems plausible that younger children demonstrate less control over DB associated movements. Another possible explanation for these findings is that a transition occurs at six years of age from overall global postural control to the selective control of independent body segments [10]. It has been suggested that overall, natural biological maturation affects FMS development and these changes, which appear through growth, can be quantitative, namely new skills, or qualitative, such as improvements in already developed abilities [3], although learning and experience have a very important role to play. However, it is also worth noting that the development of DB with age may differ according to the type of test performed [27].

The influence of anthropometric characteristics, such as BMI, on DB in preschool children is less well understood. Previous studies have found conflicting results regarding this matter [28,29]. The present study found that DB skills in healthy preschool children, aged three to six years old, were not correlated with BMI, similar to previous research [30]. However, the balance parameters analysed were correlated with physical growth indicators, such as body height and body weight.

A second objective of this study was to analyse the reliability and validity of the BBT in preschool children. Our results indicate adequate reliability and validity for the BBT in this population. There was high temporal reliability (initial test/retest) and modest convergent validity between the BBT and SBST. Although the time spent offers the lowest SEM, we consider it important to take into account the variables of distance reached, time spent, and the steps taken to obtain a more precise measure of DB in this population. Moreover, this test is safe, easy to perform, and highly acceptable for preschool children. The BBT provides a simple and inexpensive tool to measure DB at an early age, and it would be valuable to perform comparative studies. Additionally, the BBT is in line with ecological approaches regarding the use of DB testing in similar conditions to real life, thus improving ecological validity. A previous study has indicated that balance beam walking displays good reliability in preschool children with regards to the parameter of time (ICC = 0.64) [27], a value which was below the result of the current study. Finally, this study provides reference values for BBT, adjusted for age and sex, recorded from a large sample of Spanish preschool children. However, the data must be interpreted with caution as typical age periods of development simply indicate a time range during which certain behaviours may be observed in the average individual. Thus, an overreliance on these time periods would contradict the concepts of continuity, specificity, and individuality in the development process [4].

The main limitation of this study is the use of a cross-sectional versus longitudinal design for measuring DB in growing children. However, the strength of this study includes its large sample size, and to our knowledge, it is the first study to provide reference values of DB testing in preschool children. Practically, reference percentile values from this study provide needed comparative data for teachers, coaches, and physicians who wish to use the simple, low cost BBT to monitor DB development in preschool children. Moreover, the extreme percentiles can be used as a 'warning sign' indicating it may be necessary to conduct additional tests to identify possible motor delays or for screening children with extremely good dynamic balance performance.

In conclusion, no differences in BBT performance were found according to sex; however, age was found to influence BBT performance. The reference values established for Spanish preschool children in the current study could be used to monitor DB development. Finally, the BBT showed good reliability and validity in preschool children aged three to six.

## Declaration of Competing Interest

There were no conflicts of interest with other authors or institutions for this study.

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