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Analysis of the centre of pressure in bipedal stance among individuals with and without intellectual disabilities, individuals with Down syndrome and dancers with Down syndrome

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Abstract

Background Individuals with intellectual disabilities (IDs) often present deficiencies in motor, balance and postural control. On the other hand, the practice of physical activity and dance usually reduces these deficiencies. Therefore, in this study, we aimed to compare the control of the centre of pressure (COP) in people with Down syndrome (DS) or other causes of ID in relation to people without disabilities and to observe the influence of vision and the practice of dance.
Methods This cross-sectional study analyses the COP in a static standing position with open and closed eyes in four study groups. A total of 273 people were recruited (80 adults without ID, 46 adults with DS, 120 adults with other causes of ID and 27 dancers with DS).
Results A greater area of oscillation and path of the COP was observed in the participants with ID compared with the participants without ID, especially in the sway area of the COP. The oscillation speed of the COP was also higher. When analysing the displacement of the COP, anteroposterior and mediolateral components, there were also differences, except when comparing the group of dancers with DS with respect to the group without ID. The visual condition only influenced the group of participants without disabilities.
Conclusions The results of our study show that there is a less efficient static postural control in people with ID, as greater displacements were observed in the COP of the participants with ID. The differences in some specific variables that analyse the displacement of the COP were smaller when comparing the group of dancers with DS and the individuals without ID.

Keywords dance, Down syndrome, intellectual disability, pressure centre, static balance

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Introduction

The American Association on Intellectual and Developmental Disabilities has defined intellectual disability (ID) as a condition characterised by significant limitations in intellectual functioning and adaptive behaviour, which covers everyday practical and social skills and appears before the age of 22 (Schalock *et al.* 2021). People with ID often have more difficulties with balance, gait and postural control than typically developing individuals. These aspects can be trained with specific physical activity interventions to improve their physical condition and improve balance and mobility parameters, thus reducing falls throughout their lives (Enkelaar *et al.* 2012; Garrido Martínez & Cruzado 2020).

Down syndrome (DS), also known as trisomy 21, is a genetic disorder that causes ID (Antonarakis *et al.* 2020; Bull 2020). People with DS present their own morphological, neurofunctional and psychomotor characteristics such as slow motor skills, tonic-postural dysfunction, slow balance and motor reactions, as well as muscle hypotonia, ligamentous laxity and reduced muscle strength (Concolino *et al.* 2006; Angulo-Barroso *et al.* 2008). Postural instability requires specific assessments using measurement instruments such as force platforms and stabilometry to assess parameters such as the centre of pressure (COP). Studies with these measuring instruments show COP recordings in static standing as tools of acceptable reliability to analyse postural control and balance in people with ID and specific visual conditions (Pineda *et al.* 2020). Postural sway is analysed through the oscillation area, travel distance of the COP and the speed or oscillation frequency of the COP (Ruhe *et al.* 2010; Blomqvist *et al.* 2012; Pineda *et al.* 2020). Regarding the oscillation area, it is interesting to distinguish between anteroposterior (AP) and mediolateral (ML) displacements, taking into account the predominance of the dominant lower extremity, right or left. Postural control in people with DS in relation to subjects from the general population shows a greater oscillation and length of AP and ML trajectory of their COP (Villarroya *et al.* 2012; Wang *et al.* 2012; Zago *et al.* 2019, 2020). Apart from the influence of neurological factors, COP can be influenced by typical morphological causes of people with DS, such as plantar morphology or flat feet, ankle positioning and plantar flexion and muscular hypotonia. All of this contributes to changes in AP and ML displacements, so a balance and gait deficit is therefore manifested (Galli *et al.* 2014).

Research with the premise of evaluating static balance in people with ID shows a comparison of the visual condition of open eyes (OE) and closed eyes (CE), taking into account that some people with ID have moderate and/or severe visual impairment and even hearing loss (Klavina & Jekabsone 2015; Klavina *et al.* 2017). The visual condition of OE and CE in the COP can be a determining factor in the displacements of the COP (Cimolin *et al.* 2011; Rigoldi *et al.* 2011; Wang *et al.* 2012; Villarroya *et al.* 2013; Biec *et al.* 2014; Gutiérrez-Vilahú *et al.* 2016; Massó-Ortigosa *et al.* 2018).

Postural control can be improved with therapeutic programmes and interventions based on physical activity training, such as isokinetic muscle strength training and postural balance (Eid *et al.* 2017). Treadmill training and individualised low-intensity and high-intensity training facilitate motor function, improve ambulation and gait and increase joint mobility of the lower extremities, although changes in individuals with DS are smaller in relation to the general population (Wu *et al.* 2007, 2010).

Dance-based physical activity training for people with ID and DS can bring great benefits at a functional, cognitive and social level (Gutiérrez-Vilahú *et al.* 2016; Massó-Ortigosa *et al.* 2018; Ramos-Paiva *et al.* 2021). Adapted or inclusive dance programmes significantly affect motor development and performance (Moraru *et al.* 2014; Reinders *et al.* 2015).

For these reasons, it is important to deepen the knowledge of COP in individuals with ID, differentiating between DS and non-DS. Considering what has been said about the role of dance, we wanted to take advantage of the opportunity to incorporate a group of people with DS who practise dance in a recreational and guided way.

The main objective of this study was to compare COP control in people with DS and other causes of ID in relation to people without ID. We also aimed to examine the impact of visual information and the potential influence of dance practice on postural control. Our research aimed to answer some important questions: (1) we investigated whether individuals with ID, regardless of the underlying cause, demonstrate distinctive postural control during standing compared with those without ID; (2) we aimed to ascertain whether DS as a specific subtype of ID significantly contributed to these potential differences; (3) furthermore, we investigated whether practising dance impacted postural control in this population; (4) additionally, we analysed the influence of visual conditions, such as OE vs. CE, on postural control during standing; (5) and we assessed whether this potential influence differs among individuals with ID, with and without DS, in comparison with those without ID.

Methods

Study problem

In light of the imperative to deepen our understanding of the characteristics and behaviour of the COP in individuals with ID, individuals with DS and dancers with DS and their differences with people without disabilities, the following describes the methodology employed to analyse and compare the characteristics and behaviour of the COP in these participants.

Study design and participants

This is a cross-sectional study that used data collected from 273 participants. Volunteers without disabilities were recruited from university campuses (n = 80, 34 ± 12 years old); individuals with ID were recruited from occupational centres (n = 46 DS, 35 ± 9 years old; n = 120 ID without DS, 48 ± 10 years old); and dancers with DS were recruited from a classical ballet school for adults with ID (n = 27, 24 ± 8 years old). The ID classification was obtained from the patients' medical records; all the participants with DS were diagnosed with mild ID according to the Spanish National Government classification (Spain 2000).

The non-dancer participants, with and without disabilities, engaged in physical activities one or two times per week for 30–45 min. The dancers with DS trained at least three times a week for 1 h during the last 3 years. The dance programme followed the structure of classical ballet classes, with barre and centre exercises and choreographic rehearsals.

All participants were able to walk without aids and did not present motor impairments and/or severe vestibular and/or vision impairments. Participants using medication that may affect balance or those who could not tolerate the study and/or follow instructions were not included in the study.

Procedures

A total of 60 adults with DS, 140 adults with ID, 97 adults without disabilities and 50 dancers with DS and their parents/legal guardians were invited to a first meeting where we explained the testing procedures and the period of time required for the study. At the end of the initial meeting, participants and parents/legal guardians were given time to read the study information sheet and ask any questions to clarify their doubts. Finally, all of those who agreed to participate in the study signed the informed consent. After signing the informed consent, a health screening questionnaire was completed by each participant and/or the participant's parent(s) and/or legal guardian. During the second meeting, all the assessments were carried out.

The study was approved by the Institutional Research Ethics Committee and follows the Helsinki guidelines for ethical behaviour (ethical code: URL 2014_2015_010).

Assessments

Anthropometric assessments

Height was measured to the nearest 0.1 cm using a stadiometer (Seca 225, Seca, Hamburg, Germany). Weight was measured to the nearest 0.1 kg on a digital scale (Seca 861, Seca), with the subject wearing lightweight clothing and no shoes. Body mass index (BMI) was calculated as weight in kilograms divided by height in metres squared.

Static standing balance assessments

As in a previous study (Oviedo *et al*. 2014), postural sway was assessed with a pressure platform (Podoprint Balance Platform, Namrol, Barcelona, Spain). All participants performed a double leg stance with OE and CE. Participants were instructed to stand erect on the platform with no shoes, motionless and with their arms by their sides. Heels were separated by 3 cm, and toes formed a 30° angle. The software requires each participant to maintain this position for 52 s. Three trials were performed with a 60-s rest between trials; the best of these was used for the analysis. Total travel distance (TTD), radial area (RA), ratio between TTD and RA (TTD/RA), mean COP velocity (total length of the COP path per unit time), the mean ML COP oscillation velocity (Lat_Vel), the mean AP COP oscillation velocity

(AP_Vel), mean ML (MLD) and mean AP (APD) displacements of the COP and the distance from the ordinate origin (mean X and mean Y) (theoretical point where the COP should be) to the point at which the COP is located were measured at a frequency of 100 Hz using the manufacturer's specific software (Podoprint v2.6, Namrol).

Statistical analysis

Descriptive statistics were obtained for all variables. The variables of interest (TTD, RA, TTD/RA, COP velocity, COP Lat_Vel, COP AP_Vel, the MLD and the APD of the COP and the distances mean X and mean Y) were analysed and compared between the four study groups. The possible changes in relation to the different vision conditions (OE and CE) were also analysed in each group.

To check the normality of the data, the Kolmogorov–Smirnov and Shapiro–Wilk normality tests were used. As the data were not normally distributed, we based our analysis on non-parametric tests. For the between-group comparisons, the Kruskal–Wallis tests were performed (and adjusted with the Bonferroni test for multiple comparisons), and the difference between means was tested using the Mann–Whitney *U*-test. Between-group comparisons were adjusted by using the variables age and BMI.

Finally, the Wilcoxon matched pairs signed-rank test was used to analyse within-group differences at different conditions (OE vs. CE). As a measure of the effect size, it has been considered to use the *Z*-value parameter (Wilcoxon's test statistic) divided by the square root of the sample (rbis). The interpretation of this value is similar to Cohen's (1992) *d*: 0.2 small effect, 0.5 medium effect and 0.8 large effect (Wilcox & Muska 1999).

The critical values for statistical significance were assumed to be at an alpha level < 0.05. Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) v25.0 (IBM SPSS Statistics, Chicago, IL, USA).

Results

Descriptive data

There were differences in age between groups. The ID group was the oldest, and the dancers with DS group were the youngest.

Some anthropometric differences were observed between groups in terms of height, weight and BMI (Table 1). Among them, the DS and ID groups had a higher BMI than the control group. We also found a lower BMI in the dancers with DS compared with the non-dancer participants with DS. Shorter heights were also observed in all groups with ID compared with the control group and in the DS groups compared with the group of individuals with ID but without DS. Regarding weight, it was lower in the control group compared with the rest of the groups with ID and lower in the dancers with DS group compared with the DS and ID groups. In the group of dancers with DS, it was not possible to perform the test with CE in two of the participants due to difficulty maintaining the posture and the time required.

Between-group comparisons

Open eyes condition

Table 2.1 presents the comparison between-group of the COP's displacements under the OE condition. The TTD of the COP's trace line was greater in the DS, dancers with DS and ID groups compared with the control group. The RA was only different in the ID group compared with the control group.

The TTD/RA ratio was lower in the DS and ID groups compared with the control group. Additionally, the ratio was lower in the ID group compared with the dancers with DS group.

The mean COP velocity, its Lat_Vel and its AP_Vel were higher in the DS, ID and dancers with DS groups compared with the control group. The MLD and the APD were greater only in the DS and ID groups compared with the control group.

Closed eyes condition

Table 2.2 presents the comparison between-group of the COP's displacements under the CE condition. The COP's TTD in the DS and ID groups was greater than in the control group. The RA was greater in the DS group compared with the control group.

The TTD/RA ratio was lower in both the DS and ID groups compared with the control group. In addition, the TTD/RA ratio of the ID group was lower than that of the dancers with DS group.

The mean COP velocity, its Lat_Vel and its AP_Vel were higher in both the DS and ID groups compared

Table 1 Participants' characteristics

Variables	1: DS (*N* = 46)		2: ID (*N* = 120)		3: Control group (*N* = 80)		4: Dancers with DS (*N* = 27)		All (*N* = 273)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P*-value	Differences between groups
Age (years)	35	9	48	10	34	12	24	8	39	13	<0.001	1 vs. 2†; 1 vs. 4**; 2 vs. 3†; 2 vs. 4†; 3 vs. 4†
Sex (male/female)	28/18		71/49		38/42		17/10		154/119		0.284	–
Weight (kg)	67.09	11.43	73.53	14.84	68.96	14.14	55.57	14.83	69.33	14.99	<0.001	1 vs. 4**; 2 vs. 4†; 3 vs. 4†
Height (m)	1.55	0.08	1.62	0.11	1.70	0.09	1.50	0.10	1.62	0.12	<0.001	1 vs. 2†; 1 vs. 3†; 2 vs. 3†; 2 vs. 4†; 3 vs. 4†
BMI (kg/m^2)	28.08	4.39	28.20	5.80	23.87	4.15	24.48	5.38	26.54	5.46	<0.001	1 vs. 3†; 1 vs. 4*; 2 vs. 3†; 2 vs. 4**

*$P < 0.050$.
**$P < 0.010$.
†$P < 0.001$.
DS, Down syndrome; ID, intellectual disability without DS; BMI, body mass index.

with the control group. As in the OE condition, the MLD and the APD were greater in both the DS and ID groups compared with the control group.2.2

Intra-group comparisons according to the condition (open eyes or closed eyes)

The comparisons between OE and CE within the same group are presented in Tables 3.1–3.4. In the DS group, the mean COP velocity and its AP_Vel were greater in the CE condition, while the mean Y distance was greater in the OE condition.

In the ID group, the TTD/RA ratio and the AP_Vel were greater in the CE condition, while the MLD was greater in the OE condition.

In the control group, the RA and the APD were greater in the OE condition, while the TTD/RA ratio and the mean X distance were greater in the CE condition.

In the dancer with DS group, the TTD, RA, mean COP velocity, Lat_Vel and APD displacement were greater in the OE condition.

Discussion

Some anthropometric differences were found between groups in terms of height, weight and BMI. Among them, we observed higher values of BMI in the DS and ID groups compared with the control group. Moreover, it was noticed that the BMI was lower in the group of dancers with DS than that of the DS group who did not practise. This difference may be attributed to factors like age, physical activity levels or unaccounted variables, such as potential differences in dietary habits, within the dancing group.

Shorter heights were also observed in all groups compared with the control group and in the DS groups compared with the rest of the individuals with ID. Regarding weight, it was lower in the control group compared with the rest of the groups and lower in the dancers with DS group compared with the non-dancer DS and ID groups.

Between-group comparisons

Open eyes condition

Both the length and area (TTD and RA) of the COP's trace lines were greater in the DS, dancers with DS

Table 2.1 Between-group comparisons of centre of pressure displacements with open eyes

Variables	1: DS (N = 46) Median (P25/P75)	2: ID (N = 120) Median (P25/P75)	3: Control group (N = 80) Median (P25/P75)	4: Dancers with DS (N = 27) Median (P25/P75)	Total (N = 273) Median (P25/P75)	H-value	P-value	Between-group differences
Total travel distance (mm)	139.96 (112.32/180.12)	127.22 (91.99/197.39)	95.97 (59.32/130.11)	132.65 (107.17/193.12)	121.29 (88.44/163.55)	76.00	<0.001	1 vs. 3†; 2 vs. 3†; 3 vs. 4**
Radial area (mm^2)	46.06 (25.48/96.08)	51.07 (21.57/140.83)	14.75 (7.99/26.94)	23.25 (13.49/68.86)	29.72 (14.55/78.96)	117.74	0.001	2 vs. 3†
TTD/RA ratio (1/mm)	3.01 (1.45/5.35)	2.32 (1.28/4.52)	5.61 (3.48/10.58)	4.95 (2.67/8.27)	3.56 (1.79/6.45)	105.71	<0.001	1 vs. 3*; 2 vs. 3†; 2 vs. 4*
COP velocity (mm/s)	2.42 (1.95/3.09)	2.20 (1.58/3.43)	1.79 (1.26/2.30)	2.31 (1.89/3.33)	2.14 (1.59/2.86)	59.34	<0.001	1 vs. 3**; 2 vs. 3†; 3 vs. 4**
COP mediolateral velocity (mm/s)	1.86 (1.47/2.35)	1.62 (1.18/2.48)	1.42 (0.95/1.84)	1.84 (1.51/2.36)	1.64 (1.21/2.17)	45.53	<0.001	1 vs. 3**; 2 vs. 3†; 3 vs. 4**
COP anteroposterior velocity (mm/s)	1.60 (1.19/2.17)	1.48 (1.00/2.18)	1.07 (0.75/1.35)	1.27 (1.03/2.03)	1.32 (0.97/1.82)	73.58	<0.001	1 vs. 3†; 2 vs. 3†; 3 vs. 4**
MLD (mm)	1.22 (0.83/2.09)	1.41 (0.89/2.50)	0.77 (0.50/1.04)	1.05 (0.65/1.60)	1.10 (0.69/1.88)	92.43	<0.001	1 vs. 3*; 2 vs. 3†
APD (mm)	1.59 (1.18/2.82)	1.69 (1.12/2.80)	0.98 (0.68/1.43)	1.34 (0.73/2.39)	1.38 (0.91/2.30)	74.49	<0.001	1 vs. 3*; 2 vs. 3†
Mean X distance (mm)	4.92 (−0.20/13.86)	4.34 (−1.50/11.33)	2.07 (−1.49/6.87)	2.79 (−1.48/10.87)	3.23 (−1.36/9.94)	12.62	0.136	–
Mean Y distance (mm)	−5.67 (−10.07/0.40)	−5.58 (−12.11/1.46)	−8.46 (−12.56/−3.06)	−0.78 (−10.58/3.24)	−6.09 (−11.86/0.39)	13.30	0.151	–

*$P < 0.050$.
**$P < 0.010$.
$^{\dagger}P < 0.001$.
DS, Down syndrome; ID, intellectual disability; TTD, total travel distance; RA, radial area; COP, centre of pressure; MLD, mediolateral displacement; APD, anteroposterior displacement.

Table 2.2 Between-group comparisons of centre of pressure displacements with closed eyes

Variables	1: DS (*N* = 44) Median (P25/P75)	2: ID (*N* = 120) Median (P25/P75)	3: Control group (*N* = 80) Median (P25/P75)	4: Dancers with DS (*N* = 27) Median (P25/P75)	Total (*N* = 271) Median (P25/P75)	*H*-value	*P*-value	Between-group differences
Total travel distance (mm)	155.18 (122.66/197.78)	128.57 (93.32/201.19)	95.97 (67.02/125.62)	127.30 (106.69/151.69)	121.32 (91.33/161.93)	46.67	<0.001	1 vs. 3†; 2 vs. 3†
Radial area (mm^2)	48.24 (24.56/96.54)	44.73 (19.55/146.82)	13.43 (6.76/21.32)	23.04 (12.699/56.424)	26.66 (13.64/77.70)	67.74	0.019	1 vs. 3*
TTD/RA ratio (1/mm)	3.73 (1.64/5.70)	2.74 (1.46/4.77)	6.81 (4.00/12.52)	5.49 (3.120/8.268)	4.03 (1.89/6.94)	58.53	<0.001	1 vs. 3†; 2 vs. 3†; 2 vs. 4*
COP velocity (mm/s)	2.69 (2.11/3.45)	2.24 (1.59/3.47)	1.77 (1.32/2.26)	2.23 (1.867/2.611)	2.14 (1.65/2.76)	37.32	<0.001	1 vs. 3†; 2 vs. 3**
COP mediolateral velocity (mm/s)	1.87 (1.49/2.38)	1.63 (1.16/2.48)	1.40 (0.95/1.76)	1.77 (1.474/2.162)	1.64 (1.20/2.11)	26.28	0.001	1 vs. 3**; 2 vs. 3*
COP anteroposterior velocity (mm/s)	1.70 (1.33/2.48)	1.55 (1.02/2.34)	1.06 (0.78/1.34)	1.27 (1.063/1.837)	1.34 (1.00/1.90)	48.81	<0.001	1 vs. 3†; 2 vs. 3†
MLD (mm)	1.33 (0.84/2.02)	1.25 (0.85/2.45)	0.70 (0.45/1.01)	1.05 (0.647/1.600)	1.03 (0.66/1.79)	49.29	<0.001	1 vs. 3**; 2 vs. 3**
APD (mm)	1.54 (1.16/2.51)	1.63 (1.13/2.78)	0.89 (0.62/1.18)	1.16 (0.724/1.818)	1.28 (0.87/1.96)	60.75	<0.001	1 vs. 3†; 2 vs. 3†
Mean X distance (mm)	4.02 (−0.28/15.98)	3.78 (−1.54/11.23)	2.25 (−0.59/7.43)	2.96 (−1.484/8.280)	2.98 (−1.14/9.49)	3.88	0.291	–
Mean Y distance (mm)	−5.38 (−9.15/0.20)	−4.55 (−11.55/2.13)	−8.28 (−12.17/−3.49)	−0.40 (−10.338/4.459)	−6.03 (−11.39/0.13)	9.07	0.052	–

*$P < 0.050$.
**$P < 0.010$.
†$P < 0.001$.
DS, Down syndrome; ID, intellectual disability; TTD, total travel distance; RA, radial area; COP, centre of pressure; MLD, mediolateral displacement; APD, anteroposterior displacement.

Table 3.1 Comparison of the displacements of the centre of pressure according to visual conditions (open eyes vs. closed eyes) in the Down syndrome group

Variables	OE (N = 46) Median (P25/P75)	CE (N = 44) Median (P25/P75)	P-value	Z-value	rbis
Total travel distance (mm)	138.43 (107.33/172.09)	155.18 (122.66/197.78)	0.007	−2.68	0.16
Radial area (mm^2)	45.58 (25.59/96.08)	48.25 (24.56/96.54)	0.632	−0.48	0.03
TTD/RA ratio (1/mm)	2.98 (1.41/4.40)	3.73 (1.65/5.70)	0.632	−0.48	0.03
COP velocity (mm/s)	2.40 (1.86/2.95)	2.69 (2.11/3.45)	0.004	−2.84	0.17
COP mediolateral velocity (mm/s)	1.84 (1.47/2.34)	1.88 (1.49/2.38)	0.169	−1.38	0.08
COP anteroposterior velocity (mm/s)	1.47 (1.15/2.08)	1.70 (1.34/2.48)	0.001	−3.47	0.21
MLD (mm)	1.21 (0.83/2.14)	1.33 (0.84/2.02)	0.442	−0.77	0.05
APD (mm)	1.77 (1.18/2.87)	1.54 (1.16/2.51)	0.516	−0.65	0.04
Mean X distance (mm)	5.85 (0.07/13.29)	4.02 (−0.28/15.98)	0.484	−0.70	0.04
Mean Y distance (mm)	−6.51 (−11.12/0.40)	−5.38 (−9.15/0.20)	0.022	−2.28	0.14

OE, open eyes; CE, closed eyes; TTD, total travel distance; RA, radial area; COP, centre of pressure; MLD, mediolateral displacement; APD, anteroposterior displacement.

Table 3.2 Comparison of the displacements of the centre of pressure according to visual conditions (open eyes vs. closed eyes) in the intellectual disability without Down syndrome group

Variables	OE (N = 120) Median (P25/P75)	CE (N = 120) Median (P25/P75)	P-value	Z-value	rbis
Total travel distance (mm)	126.65 (186.97/88.04)	128.57 (93.32/201.19)	0.175	1.36	0.08
Radial area (mm^2)	56.50 (133.50/25.02)	44.73 (19.55/146.82)	0.675	0.42	0.02
TTD/RA ratio (1/mm)	2.15 (3.83/1.15)	2.74 (1.46/4.77)	0.01	2.57	0.16
COP velocity (mm/s)	2.17 (3.24/1.53)	2.24 (1.59/3.47)	0.152	1.43	0.09
COP mediolateral velocity (mm/s)	1.62 (2.47/1.19)	1.63 (1.16/2.48)	0.634	0.48	0.03
COP anteroposterior velocity (mm/s)	1.42 (2.07/0.97)	1.55 (1.02/2.34)	0.001	3.39	0.21
MLD (mm)	1.50 (2.61/0.94)	1.25 (0.85/2.45)	0.033	2.13	0.13
APD (mm)	1.83 (2.89/1.11)	1.63 (1.13/2.78)	0.205	1.27	0.08
Mean X distance (mm)	5.11 (11.38/−1.46)	3.78 (−1.54/11.23)	0.511	0.66	0.04
Mean Y distance (mm)	−5.91 (1.17/−12.37)	−4.55 (−11.55/2.13)	0.057	1.90	0.12

OE, open eyes; CE, closed eyes; TTD, total travel distance; RA, radial area; COP, centre of pressure; MLD, mediolateral displacement; APD, anteroposterior displacement.

and ID groups compared with the control group. These findings are consistent with previous studies in which less postural control in standing is usually observed in individuals with DS or other causes of ID compared with the population without ID (Webber *et al.* 2004; Galli *et al.* 2008; Cimolin *et al.* 2011; Klavina *et al.* 2017; Zago *et al.* 2020).

The TTD/RA ratio was lower in the ID and DS (excluding dancers with DS) groups compared with the control group. This indicates that the COP has a larger surface occupation in relation to its path or distance, which may be accompanied by a lower proportion of oscillations in these groups. We hypothesise that this phenomenon may be associated with a more rigid behavioural pattern characterised by fewer fluctuations and displacements in relation to the centre of the occupied area. Further investigation more focused on these parameters and a larger sample size could provide a more comprehensive understanding of this aspect. Regarding the higher values of the mean COP velocity observed in the ID, DS and dancers with DS groups when compared with

Table 3.3 Comparison of the displacements of the centre of pressure according to visual conditions (open eyes vs. closed eyes) in the control group

Variables	OE (*N* = 80) Median (P25/P75)	CE (*N* = 80) Median (P25/P75)	*P*-value	*Z*-value	rbis
Total travel distance (mm)	97.03 (55.84/135.05)	95.98 (67.02/125.62)	0.475	0.71	0.04
Radial area (mm^2)	16.16 (9.70/35.60)	13.43 (6.76/21.32)	0.011	2.56	0.15
TTD/RA ratio (1/mm)	5.11 (3.13/8.66)	6.81 (4.00/12.52)	0.004	2.90	0.18
COP velocity (mm/s)	1.84 (1.17/2.36)	1.77 (1.33/2.26)	0.421	0.80	0.05
COP mediolateral velocity (mm/s)	1.44 (0.94/1.87)	1.40 (0.95/1.76)	0.136	1.49	0.09
COP anteroposterior velocity (mm/s)	1.07 (0.68/1.38)	1.06 (0.78/1.34)	0.676	0.42	0.02
MLD (mm)	0.81 (0.59/1.13)	0.70 (0.45/1.01)	0.073	1.79	0.11
APD (mm)	1.13 (0.80/1.86)	0.89 (0.62/1.19)	<0.001	3.93	0.24
Mean X distance (mm)	1.62 (−2.10/6.75)	2.25 (−0.59/7.43)	0.004	2.88	0.17
Mean Y distance (mm)	−9.37 (−13.59/−2.00)	−8.28 (−12.17/−3.49)	0.969	0.04	0.00

OE, open eyes; CE, closed eyes; TTD, total travel distance; RA, radial area; COP, centre of pressure; MLD, mediolateral displacement; APD, anteroposterior displacement.

Table 3.4 Comparison of the displacements of the centre of pressure according to visual conditions (open eyes vs. closed eyes) in the group of dancers with Down syndrome

Variables	OE (*N* = 27) Median (P25/P75)	CE (*N* = 27) Median (P25/P75)	*P*-value	*Z*-value	rbis
Total travel distance (mm)	133.89 (107.17/203.03)	127.30 (106.69/151.69)	0.017	2.38	0.14
Radial area (mm^2)	23.47 (14.43/87.79)	23.04 (12.70/56.42)	0.014	2.45	0.15
TTD/RA ratio (1/mm)	4.94 (2.13/8.62)	5.49 (3.12/8.27)	0.259	1.13	0.07
COP velocity (mm/s)	2.35 (1.89/3.52)	2.23 (1.87/2.61)	0.013	2.49	0.15
COP mediolateral velocity (mm/s)	1.91 (1.51/2.93)	1.77 (1.47/2.16)	0.002	3.09	0.19
COP anteroposterior velocity (mm/s)	1.28 (1.03/2.30)	1.27 (1.06/1.84)	0.084	1.73	0.10
MLD (mm)	1.05 (0.64/1.63)	1.05 (0.65/1.60)	0.673	0.42	0.03
APD (mm)	1.55 (0.77/3.48)	1.16 (0.72/1.82)	0.007	2.68	0.16
Mean X distance (mm)	2.18 (−1.62/11.35)	2.96 (−1.48/8.28)	0.13	1.51	0.09
Mean Y distance (mm)	−1.10 (−11.59/1.96)	−0.40 (−10.34/4.46)	0.061	1.87	0.11

OE, open eyes; CE, closed eyes; TTD, total travel distance; RA, radial area; COP, centre of pressure; MLD, mediolateral displacement; APD, anteroposterior displacement.

the control group, which is concordant with the greater TTD, it shows a lower motor control of the static standing position in all ID groups.

The APD and the MLD were greater in the groups with DS and ID compared with the control group, although no significant differences were observed in these components between the control group and the dancers with DS group. Therefore, there are variations in both directions. Various studies have analysed these components, with a variety of results. In some cases, differences in amplitude have been observed in terms of the APD but not in the MLD (Cabeza-Ruiz *et al.* 2016). The same authors also found differences in the strength of the musculature involved in AP and ML displacements, indicating a greater activation of these muscles. In our study, muscle strength was not assessed, but in a previous study, we observed a high level of activation of the musculature involved in the MLD (Massó-Ortigosa *et al.* 2018). In that study, we did not assess the musculature involved in a static standing position. However, during gait, we observed a higher MLD due to different motor patterns at the hip level (Galli *et al.* 2008; Cimolin *et al.* 2011; Biec *et al.* 2014).

The mean COP velocity was higher in the three groups compared with the control group, both in its AP component and in its ML component. Therefore, there is a different pattern of COP velocity, which could be characterised by a higher oscillation frequency. Galli *et al.* (2008) also found differences in both directions in terms of displacement frequency. This seems to be consistent with the aforementioned result regarding the TTD/RA ratio.

We think that this behaviour of the COP, tending to occupy a greater area but with less travel in proportion, corresponds to rigid behaviour. It agrees with the findings of various electromyographic studies, in which a higher degree of muscle activation (Massó-Ortigosa *et al.* 2018) and agonist–antagonist co-activation (Carvalho & Almeida 2009) has been observed, especially in muscles that control the ankle in the AP direction, such as the tibialis anterior and the medial gastrocnemius. This is not observed in other muscle pairs at the hip and trunk levels (Carvalho & Almeida 2009). On the other hand, the same authors observed a lower modulation of the level of contraction based on changes in direction. There would therefore be more co-contraction but less variation and adaptability. In preadolescents with DS, other authors have observed different control strategies at the ankle level compared with the control group (Zago *et al.* 2021).

The causes of postural instability in people with DS have been the subject of various analyses. For a number of authors, the cerebellum and proprioception play an important role (Moldrich *et al.* 2007; Carvalho & Almeida 2009). There are even analyses of peripheral sensory action potentials, in which the amplitudes are lower in the case of people with DS (Brandt & Rosén 1998). A factor to consider would also be the quality of postural reflexes, in which the peripheral sensory and motor pathways take part (Shumway-Cook & Woollacott 1985; Massó-Ortigosa *et al.* 2019).

It is noteworthy that in some of these comparisons between groups (TTD/RA, APD and MLD), there are no differences between dancers with DS and controls, but there are differences in DS vs. control and ID vs. control. The lateral and anterior variations are greater in the DS and ID groups compared with the control group, but not in the case of the dancers with DS group. It could be that the scheduled practice of dance exerted some effect on the postural control strategy (more variation means greater travel in the corresponding direction). Previous studies have also found similar results (Gutiérrez-Vilahú *et al.* 2016). Other authors have shown improvements in stability following exercise interventions. However, these studies included walking and/or treadmill training as physical activity instead of dance programmes (Smith *et al.* 2007; Cimolin *et al.* 2011). Finally, in this study, information on posture has also been obtained, given that the position of the COP is measured with respect to the theoretical position that it should have.

Closed eyes condition

In CE, differences between groups also exist as in OE, with some variations: in CE, the TTD and COP velocity are greater in the ID and DS groups vs. the control group, but not in the dancers with DS group vs. the control group.

Intra-group comparisons according to the condition (open eyes or closed eyes)

The TTD and the mean COP velocity were greater in the CE condition in the DS group. In the ID group, the mean COP velocity and the TTD/RA ratio were greater in the CE condition, but the MLD was lower in the CE condition.

In contrast, important parameters such as TTD, RA, APD, mean COP velocity and Lat_Vel were greater in the OE condition vs. the CE condition in the dancers with DS group.

In the control group, we saw that the RA and the APD were also greater in the OE condition, but the TTD/RA ratio and the mean X distance were greater in the CE condition.

We believe it is possible that a security strategy can be generated with CE. A greater use of proprioception is possible, as is a different muscular behaviour aimed at greater muscle stabilisation effort.

In previous studies, we have seen that the group with DS did not show any differences in the behaviour of the COP according to the visual condition, but they did appear after having followed a dance-training programme (Gutiérrez-Vilahú *et al.* 2016). Furthermore, Klavina *et al.* (2017), who assessed the COP in children with and without disabilities, also found better control in OE than CE, both in people with ID and in those without ID.

Results from this study confirmed that individuals with ID, with or without DS, exhibit less efficiency in static posture with greater displacements of the COP when compared with individuals without disabilities. Conversely, it appears that among individuals with DS who engage in regular dance practice, some of these differences compared with participants without disabilities are relatively smaller.

Limitations

This study has some limitations. First, the duration of the test was 52 s, which makes it difficult to compare with other studies that employed a different methodology for the data acquisition. Second, we did not recruit an equal number of participants per group. Nevertheless, Pineda *et al.* (2020) reported that including at least 32 participants per analysed group would be sufficient to obtain valid results. In addition, it must be considered that many studies have used very small cohorts (Zago *et al.* 2020) and that it is difficult to recruit large groups of individuals with ID. Finally, the results obtained could have been affected by the difference in the number of participants recruited in each group.

Conclusions

Individuals with ID, including DS, exhibit variations in COP behaviour when analysed in a static bipedal position compared with those without ID. These variations indicate poorer postural control, both in the OE condition and in the CE condition. However, individuals with DS who regularly practise dance show relatively smaller differences, especially in the CE condition.

In the CE condition, people without ID diminish the amplitude and area of oscillation of their COP, probably as a safety strategy. However, changes observed in people with ID and DS are different, with a tendency to increase velocity and distance in CE conditions. In contrast, dancers with DS diminish TTD, RA and mean COP velocity in the CE condition.

Maintaining postural control while standing is crucial for performing daily activities, engaging in sports and socialising. Postural control while standing is important for activities of daily living, sports and social activities. We strongly believe that individuals with ID can improve their postural control through fun and sporty activities that promote it. Thus, incorporating dance as a therapeutic activity for individuals with ID may have a positive impact on postural control. Dance can be a playful and enjoyable way to improve postural control. In addition, this activity may enhance sensory and visual integration by challenging the motor control system.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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