Postural stability of adults with Down syndrome – differences between women and men

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Objective: This study aimed to analyse differences in postural stability (PS) between adults with Down syndrome (DS) and adults without DS of the same age and to compare the PS between men and women with DS.

Methods: Twenty-six individuals with DS (mean age 38.4 ± 8.7 yrs.) and 26 individuals without DS (mean age 38.8 ± 9.2 yrs.) participated in the study. Postural stability was measured using a pressure sensing platform MobileMat 3140 (Tekscan) in these modifications of the bipedal stance: a. wide base of support with the eyes open (WO); b. wide base of support with the eyes closed (WC); c. narrow base of support with the eyes open (NO). Six parameters of PS were compared in the statistical analysis: centre of pressure (COP) path length, COP excursion front-back, COP excursion left-right, COP velocity average, time to boundary (TTB) front-back, and TTB left-right.

Results: Most PS variables (COP path length, COP excursion left-right, COP velocity average, TTB front-back) indicate significantly lower PS of adults with DS than that of the reference group ($p<0.05$). Some PS variables (COP path length and COP velocity average in WC, COP excursion front-back and COP excursion left-right in NO) showed differences between men and women in more demanding conditions, indicating lower PS in men with DS.

Keywords: Trisomy 21, balance, posturography, pressure sensing platform, centre of pressure, stabilogram.

Introduction

Down syndrome is one of the most common chromosomal disorders (Crawford and Dearmun 2016). Its prevalence in Europe has been estimated at 5.7 in 10,000 (de Graaf *et al*. 2021). Down syndrome (DS) is caused by trisomy of Homo sapiens chromosome 21 (Antonarakis *et al.* 2020). Trisomy 21 occurs either by nondisjunction, with the presence of 47 chromosomes, or by translocation of an additional chromosome 21 to another chromosome (Bull 2020). The extra genetic material causes alterations in the embryological development that result in several cognitive and physical characteristics that are known as of DS (Eckdahl 2017). These usually include short stature, a higher concentration of type VI collagen (resulting in an increased ligament laxity) and muscle hypotonia which may cause many musculoskeletal problems such as atlantoaxial instability, scoliosis, hip abnormalities, patella instability and flat feet (Evans-Martin 2009, Eckdahl 2017, Foley *et al.* 2019, Fergus 2021). Furthermore, direct consequences of muscle hypotonia and ligament hyperlaxity involve muscle cocontraction insufficiency, hypermobility and impaired proprioceptive reversal binding (Lauteslager *et al.* 1998).

All the above-mentioned characteristics may result in instability and therefore impaired gait pattern (Galli *et al.* 2008a, Salami *et al.* 2014, Agiovlasitis *et al.* 2015). In a systematic review by Zago et al. (2020), majority of the analysed studies focused on the gait analysis while one third of them evaluated postural control during standing.

Several studies (Galli *et al.* 2008b, Rigoldi *et al.* 2011, Villarroya, 2012, Wang *et al.* 2012) have shown that in comparison to age matched individuals, people with DS have decreased postural stability (PS). Postural instability in people with DS during quiet standing is usually characterized by greater displacement of the centre of pressure (Webber *et al.* 2004, Galli *et al.* 2008b, Cimolin *et al*. 2011), which represents lower PS (higher value means longer trajectory which indicates lower PS), especially during body sway in the mediolateral and anteroposterior directions (Galli *et al.* 2008b, Rigoldi *et al.* 2011, Villarroya, 2012, Wang *et al.* 2012).

Most of the available studies evaluated static PS during the natural bipedal stance in two conditions – open eyes and closed eyes. However, the natural bipedal stance is not representing more challenging situation for static PS required during activities of daily living. Our search did not yield any study evaluating a narrow bipedal stance. Furthermore, in terms of differences between men and women in PS, studies comparing PS have not shown a difference between female and male children and adolescents (Vuillerme *et al.* 2001, Leite *et al.* 2018). Pau *et al.* (2019) and Zago *et al.* (2019) described more impaired parameters in gait analysis for females with DS compared to males with DS. However, to the best of our knowledge, no study has ever examined these differences in adults with DS.

Therefore, the aim of this work is to evaluate and compare static PS during the natural bipedal stance and the more challenging narrow bipedal stance in adults with DS and age matched adults without DS. The second aim of this study is to compare the PS parameters between adult men with DS and adult women with DS.

Materials and Methods

This is a cross-sectional analytical study. The sample was purposive regarding age and male-female ratio to ensure equal representation amongst groups.

Participants

Fifty-two people were included in this study. Both groups were matched: DS group (n=26) consisted of 11 women and 15 men; non-DS group (n=26) consisted of 11 women and 15 men. Descriptive data (age and anthropometric characteristics) about both groups are presented in Table 1.

Individuals between 18-50 years were included in the study (both groups). The reason for selecting this range was the small number of potential participants, which was determined by the specific process of their recruitment. Participants in the DS group had to exhibit such intellectual abilities that they would understand the instructions for the course of measurement. Participants with diagnosed severe or profound mental retardation were therefore not included in the study.

The exclusion criteria for both groups were acute illness, injury or surgery in the previous two years, an epileptic seizure in the previous week and other neurological or movement disorders affecting PS (e.g., central, or peripheral paresis, condition after stroke, etc.). Also, the subjects were free of objectively proven musculoskeletal disorders in lower extremities. In the presence of a visual or hearing impairment, the participant was included in the study only if this impairment was compensated by a suitable compensatory aid and then the participant wore his / her commonly used visual and hearing aids during the measurement.

The selection of participants for the DS group took place in cooperation with DownSyndrom.CZ and the Society for the Support of People with Mental Disabilities. The search for participants in the non-DS group was carried out to compare the demographic data (age, male-female ratio) with the DS group. The study was approved by the Ethics Committee of Charles University, Faculty of Physical Education and Sport (protocol code 138/2019) and written informed consent was obtained from all participants before beginning the study.

Measurement

A portable MobileMatTM3140 measuring board (TekScan Inc., South Boston, Massachusetts, USA) with standard resolution and pressure mapping technology was used. It was connected to a computer where data was processed via USB cable using SportsAT software (Tekscan, 2016). The measuring plate has overall dimensions of 63.6 x 55.9 x 4.2 cm. The sensing area is 48.7 x 44.7 cm and the height of the platform in the sensing area is 0.76 cm. Scanning speed is up to 185 Hz, depending on the resolution. One pressure sensor for every cm^2 is built into the board and the range of measurable pressures is 345 to 862 kPa. The total weight of the board is 3.5 kg (Tekscan 2016, 2019). The MobileMat board has an established validity (Goetschius *et* *al.* 2018, Bickley *et al.* 2019) and reliability (Brenton-Rule *et al.* 2012, Bickley *et al.* 2019) for measurement of PS.

In our study, the following variables were monitored:

Centre of pressure (COP) movement

Measures of postural control as a movement of centre of pressure (COP) belong to commonly used ones (Palmieri *et al*., 2002, Gorjan *et al.* 2022). It is often quantified by recording the trajectory of the COP and the amplitude of COP path range (maximal distance over two points) in the anteroposterior and laterolateral directions (Quijoux 2021).

In our data, length of COP Path (LoP COP) is the total trajectory that the COP travels during measurement in cm (the higher the value, the worse the PS of the individual); COP Excursion Front-Back (Ex COP F-B) – means COP motion recording in the anteroposterior direction showing the maximum distance travelled by the COP during measurements in the anteroposterior direction in cm (the higher the value, the worse the PS of the individual); and COP Excursion Left-Right (Ex COP L-R) – means COP motion recording in the laterolateral direction showing the maximum distance travelled by the COP during measurement in the laterolateral direction in cm (the higher the value, the worse the PS of the individual);

COP velocity (vCOP)

The mean velocity of the COP is also one of the most widely used variables with high reliability, especially in the anteroposterior direction (Quijoux *et al.* 2021) which is influenced by both eyes-open and eyes-closed conditions and is predictive for the risk of falling.

In our data, COP Velocity Average (vCOP) means the average rate of change of COP position in cm/s (the higher the value, the worse the PS of the individual);

Time to boundary (TTB)

TTB measures estimate the time required for the COP to reach the boundary of the base of support if it were to continue on its instantaneous trajectory and velocity (Hertel *et al.* 2006). This parameter incorporates both spatial and temporal aspects, and has been shown to be more sensitive than the traditional measures in people with acute ankle sprain and instability. The lower TTB mean indicates that these individuals may have less time to make a postural correction for maintenance of balance over the base of support (Kim *et al.* 2019).

In our data, time to boundary in the anteroposterior direction (TTB F-B) is a parameter estimating the time required for the subject's COP to reach the supporting threshold basis (beyond which there is a risk of a fall), if it considers immediate speed and trajectory of COP in the anteroposterior direction in (s) (the higher the value, the better the PS of the individual); and similarly TTB L-R is a parameter estimating the time required for the subject's COP to reach the supporting threshold basis (beyond which there is a risk of a fall), if it considers immediate speed and trajectory of COP in the laterolateral direction in (s) (the higher the value, the better the PS of the individual) (Tekscan 2016, 2019).

Participants were tested in four consecutive bipedal modifications: stance with wide support base and open eyes (WO), stance with wide support base and closed eyes (WC), stance with narrow support base and open eyes (NO), and stance with narrow support base and closed eyes (NC).

During data collection, it was observed that for most participants with DS, the NC position was too demanding, and they were not able to maintain closed eyes during this measurement. In some cases, the researcher had to provide support to prevent the fall for ethical reasons so the measurement would not cause excessive discomfort to individuals. Participants with DS were unable to perform the test for a sufficient length of time to obtain unbiased data. The reason why they could not manage the test was a fear of falling. For this reason, data from NC position were not analysed.

Measurement process

The MobileMat board was placed on level ground in a quiet room with a minimum of disturbing factors. Our aim was to simulate as common conditions as possible during the measurement, so we did not include the warm-up in the protocol. The participants were asked to stand barefoot on the board. A series of four measurements followed, during which, the participants were instructed to stand and remain as still as possible. Instructions, however - often for DS participants - were explained in other ways so that they understand that it is necessary to be as calm as possible during the measurement. All participants tried out observed positions before the actual measurement. For wide support base stance, participants were asked to stand with feet width apart on the plate in the position which is natural for them. The position of the feet was spontaneous without any corrections and further specification of the degree of rotation. Narrow stance base was achieved by the parallel position of the feet so that the heels and toes were touching. In open-eye positions, the participants were instructed to focus their gaze at a fixed point in front of them, which was placed at eye level at a distance of 1.5m. Each PS scan lasted for 30s while the measurement started 3s after the participant took a specific position. The exact time of the break was not determined between the individual measurements, but the participants had an opportunity to relax. Each participant was measured only once, due to time constraints to avoid deterioration of concentration and to avoid the learning bias on the other hand.

Data analysis

Mean values and standard deviations (SD) were calculated for each continual variable. Because of the small sample sizes, we used non-parametric statistics. A generalized linear model with the gamma distribution was carried out to explore the effect of groups to each dependent variable separately. All the models were adjusted for age, sex, and height. A non-standardized regression coefficient B was used as the main outcome of effect size in the generalized linear models. In this case, the non-standardized regression coefficient B represents the size of difference between groups. For comparison of condition with open eyes and condition with closed eyes in a wide stance, we used Wilcoxon Matched Pairs Test. To evaluate the correlation between variables, we used Spearman Rank Order Correlation. Statistical significance was determined a priori at $\alpha = 0.05$. All the statistics were carried out using IBM SPSS Statistics 24.

Results

Differences between groups (non-DS vs. DS group)

Table 1 shows that mean age and mean weight of participants did not differ significantly. Mean height was lower in the DS group, as this is one of the phenotypic traits of DS. In addition, body mass index (BMI) differed significantly between DS group and non-DS group because of different height and higher prevalence of obesity in people with DS (Bertapelli*, et al*., 2016).

Table 2 presents the mean values and standard deviations of the monitored parameters of PS in both groups in all three measurement conditions. Values in DS individuals were almost twice as in the non-DS group. Most of the differences between DS and non-DS group were statistically significant. DS group showed a higher mean LoP COP (i.e., lower PS), Ex COP L-R, vCOP in each measurement condition. At TTB F-B measurement DS group achieved statistically significant lower values in all conditions. However, in TTB L-R this difference was significant only in WO and WC condition. The only parameter showing no significant differences between groups in all conditions was the Ex COP-F-B. In the DS group, we observed a higher variability between individual participants' performance.

Differences within groups according to difficulty of conditions

With increasing demands on the PS in the bipedal stance caused by closure of eyes, the non-DS participants showed significantly different values ($p \leq 0.05$) during all but one (Ex COP L-R) monitored parameters. Individuals with DS decreased values in most parameters of PS while having their eyes closed but these differences were not statistically significant (see Table 3 and figures 1-6). In the most demanding position (NO), both groups showed significantly lower PS in comparison to position WO.

Differences in postural stability between men and women with DS

In the comparison between men and women of the DS group only, we did not observe any differences in PS in the easiest position, i.e., wide stance with open eyes. However, in more demanding conditions (WC, NO), some variables showed differences in favour of women (LoP COP and vCOP in WC, and Ex COP F-B and Ex COP L-R in NO), see Table 4. It is important to note that all comparisons were adjusted for age and height to reflect the differences between the DS and non-DS group.

Correlation between selected variables

We also assessed the correlation between PS parameters and age, height, weight, and BMI. In the DS group, there was no significant correlation between PS and age or weight of the participants. A few parameters of PS were found to be corelated to the height of the participants in the wide stance, both in open eyes condition (Ex COP F-B: r=0.42), and in the closed eyes condition (Ex COP F-B: r=0.50; LoP COP: r=0.44; vCOP: r=0.44; TTB F-B: r= -0.39). As for BMI, there was statistically significant negative correlation only with Ex COP F-B (r= -0.45), in the condition of narrow stance with open eyes.

In the non-DS group, we found a statistically significant correlation between some of the PS parameters and age in wide stance with closed eyes (LoP COP: r=0.42; vCOP: r=0.41). In addition, there was a significant correlation between some of the PS parameters and weight in the wide stance with open eyes (TTB F-B r= -0.4) and in the narrow stance with open eyes (LoP COP: r=0.49; vCOP: r=0.47) conditions in this group. No correlation was found between PS and height, or BMI in the non-DS group.

Discussion

The aim of this study was to evaluate the static PS of adults with Down syndrome in comparison to the age-matched reference group and to assess whether there are differences between men and women with DS.

Six parameters of static PS were analysed using data obtained from a portable pressure plate. The measurement originally took place in four conditions: a wide stance with opened and closed eyes (WO, WC) and a narrow stance with opened and closed eyes (NO, NC). The rationale for assessing these four conditions was the hypothesis that foot positioning (size of the support base) as well as of the lack of visual information have an impact on the performance of PS (Safi *et al.* 2016). Moreover, a narrow-base stance with closed eyes is a good indicator of the ability to control PS in an upright stance (Véle 1997).

In our work however, NC, was found to be impracticable in the group of participants with DS. During the NC position, individuals with DS repeatedly opened their eyes. Such problems with keeping the eyes closed were also described in other studies (Vuillerme 2001, Gomes *et al.* 2007, Cabeza-Ruiz *et al.* 2011, Masso *et al.* 2013, Cabeza-Ruíz *et al.* 2016). In addition, during the NC trial, the researcher had to provide support to prevent the participants from falling or to address their fear of falling.

Our results show that in all conditions (WO, WC, NO), group of participants with DS had significantly different values in most of the measured variables except for excursions of COP in the anteroposterior direction and TTB in laterolateral direction (NO condition only). It is in agreement with Galli et al. (2008b) who showed that oscillations in anteroposterior direction are comparable to control group but are much larger in mediolateral direction. Also, it is in line with higher prevalence of a medio-lateral strategy in maintaining postural stability in people with DS (Zago *et al.* 2021). Another explanation could be that the postural mechanisms controlling the anteroposterior axis reach maturity before the mechanisms involved in controlling the mediolateral axis (Blanchet *et al.* 2019).

The biggest difference in comparison to age-matched individuals was actually in the easiest position where the values of measured parameters were about twice worse. It means that lower postural stability in people with DS could affect even easy daily tasks.

Furthermore, there was a great variability of values in the DS group, which is also visible from the figures. This is a common problem in measurements in people with special needs because of their individual differences. In our previous study with patients after bariatric surgery (Cibulkova *et al*. 2022) there was also high inter individual variability but to a lesser extent. The greatest variability was present in the parameters of COP excursions. As Palmieri *et al.* (2009) described, maximum and minimum amplitude values are likely to show great variance between trials and between subjects and may reflect rather some perturbation in the environment (eg., a noise) that influence the postural-control system.

When comparing repeated measures of PS in the more demanding position of the narrow stance, both groups decreased their performance significantly which is expectable result confirming e.g. results of systematic review of Roman-Liu (2018).

Looking at the comparison of wide stance with and without visual control (WO vs. WC) there are quite interesting results showing statistically significant difference in the non-DS group (except the laterolateral amplitude – excursion) while the DS group did not show any significant difference. It seems to be that the stability in DS group was already decreased in the easiest position so the difference was not so large. Another explanation could be an influence of more external distractions in DS group when the eyes were opened or possibly effect of new situation of measurement in this first (WO) trial. Similar results of no changes between open and closed eyes sessions in people with DS were described also by Galli *et al.* (2008b).

The observed inferior PS of people with DS is in line with earlier published studies which conclude that the population with DS shows decreased PS compared to non-DS individuals (Vuillerme *et al.* 2001, Galli *et al.* 2008b, Cimolin *et al.* 2011, Rigoldi *et al.* 2011, Villarroya *et al.* 2012, Guzman-Muňoz *et al.* 2017, Zago *et al.* 2021). This phenomenon appears to be due to the impaired proprioception caused by muscle hypotonia and ligament hyperlaxity in people with DS (Galli *et al.* 2008b).

These two characters disrupt the feedback loop that is necessary for the perception of body position (Woollacott *et al.* 1986) and, in addition, are disadvantageous for coordinating the muscles needed for stabilizing joints (Leite *et al.* 2018). Coordination disorders in people with DS were revealed in a study by Uyanik (2003), who describes how structural changes in the cerebellum and brainstem may be contributing to the disorders. One of the reasons for lower PS in people with DS could be also less frequent activation of postural patterns in all spatial directions as proposed by Zago *et al.* (2021).

In addition, PS can be affected by sensory functions – one of the symptoms of DS is sensory defect in visual focusing (accommodation) (Doyle *et al.* 2016). However, this problem is not only an issue requiring an optometry solution but there might also be features of cerebellar visual impairment (Wilton *et al.* 2021). As the vision is very important sensory input, this deficit could play a role in poor posture stabilisation (Doyle *et al.* 2016). Furthermore, people with DS also present a higher incidence of vestibular alterations in comparison to general population. These sensorimotor impairments may explain an atypical motor coordination while performing a motor action as well (Zago et al. 2021).

Moreover, people with DS also often show flat feet (Pau *et al.* 2012) and obesity (Usera *et al.* 2005, Bertapelli*, et al*., 2016). Both aspects have a negative impact on foot mechanoreceptors, and PS respectively (Bensmaia *et al.* 2005). Therefore, it might be of interest that we found significant negative correlation between BMI and anteroposterior excursions in the narrow stance with open eyes condition in the DS group. While the question of lower PS in obese people due to inconclusive research was not answered yet, the decreased PS in individuals with obesity is probably related to a different distribution of mass and thus a different centre of gravity (Villarrasa-Sapiña *et al*. 2018, Cibulková *et al.* 2022).

Poor PS may be also explained by the fact that most individuals with DS have hypoactive lifestyle leading to the insufficient opportunities to challenge their neuromuscular system (Bieć *et al.* 2014, Horvat *et al.* 2016, Agiovlasitis *et al.* 2020).

According to Capio *et al.* (2018), in people with DS, PS is related to fundamental motor skills (FMS). These authors showed that children with DS who have better balance ability tend to have more proficient FMS. On the other hand, poor balance with greater instability and inefficient compensatory mechanisms, including altered centre of pressure displacement and trunk stiffening, predispose people with DS to falls (Jain *et al.* 2022). Thus, it is important to evaluate PS and incorporate its improvement in the comprehensive rehabilitation so there is a possibility to increase motor competence and adherence to physical activity (PA).

To our knowledge, this is the first study attempting to investigate whether PS is different between adult men and women with DS. The results of our study cannot fully support the hypothesis that the PS of adult men and women with DS is significantly different. However, it seems that adult women with DS have slightly better PS than men, which is especially visible in more difficult conditions (e.g. in closed eyes or narrow stance).

Looking at differences between men and women in the wide stance with closed eyes condition, men with DS had significantly worse length of COP path and average rate of change of COP position in comparison to women with DS. On the other hand, rather excursions in both directions (i.e., COP motion recording in the entire direction showing the maximum distance travelled by the COP during measurements) were different between men and women with DS in the narrow stance. The explanation could be a different distribution of body mass and perhaps obesity type (android, gynoid) between men and women.

Similar research with younger DS population, Leite *et al.* (2018), compared the PS between boys and girls with DS aged 8 to 12 and did not find statistically significant differences (measuring area of COP and velocities in both directions). Vuillerme *et al.* (2001) compared PS in male and female adolescents with DS (mean age 16.8 years). In addition, these authors concluded that the PS of individuals with DS does not differ significantly between them. Differences between adult men and women with DS were not described in the literature before as many studies used small samples and did not differentiate between men and women.

Previous studies do not lead to a uniform conclusion regarding the differences in PS between men and women without DS. Hageman *et al.* (1995) tested the PS of men and women in two age categories (20-25 years; 60-75 years). The results of their study showed that the gender of the measured subject did not have a statistically significant effect on the values of the monitored parameters (average COP movement speed, overall COP trajectory). A study by Kim *et al.* (2012) had a similar design to the above-mentioned study. No statistically significant difference was found between PS of younger men and women (18-26 years), but older women had significantly higher mean values of COP movement speed and laterolateral COP deviation compared to older men (65-86 years).

Also, in a study by Blaszczyk *et al.* (2014) women in posturographic measurements showed a significantly higher speed of COP movement compared to men (average age 21.5 years), which indicates their inferior PS. On the contrary, we did not see such differences in our data recorded from the non-DS group.

A large study by Era *et al.* (2006) in which individuals without DS were divided into six groups according to age (30-39 years; 40-49 years; 50-59 years; 60-69 years; 70-79 years; 80+ years), revealed that in all groups, men showed a statistically significant higher rate of COP movement in the anteroposterior direction and, from the age of 50, also a significantly higher mean rate of COP movement in the laterolateral direction. These differing study conclusions may be based on inconsistent work methodologies.

Nevertheless, our results indicate that women with DS performed better than men with DS in some of the observed parameters of PS. In our sample, men were older than women by eight years on average. As shown by Era *et al.* (2006), differences in PS can be already evident when comparing people aged 30-39 with a group of people 40-49 years. Thus, it could be suggested that women's better outcomes may be due to age. However, there was no correlation between any PS parameter and age in this group. Moreover, the between-group differences were adjusted to age.

It could be argued that the number of participants in the study was low, especially when dividing the participants into subgroups (men, women). It is important to emphasize the difficulty of recruiting participants with DS (in addition to meeting the inclusion criteria). But in comparison with previous studies in DS population, where the samples contained, for example n=9 (Webber *et al.* 2004, Gomes *et al.* 2007), n=10 (Bieć *et al.* 2014), n=11 (Masso *et al.* 2013), n=12 (Cabeza-Ruiz *et al.* 2016), and n=19 participants (Cimolin *et al.* 2011), we still had a reasonably large sample.

In future research on this topic, it would be feasible to have a more detailed anamnestic and initial examination of all participants, so individuals with DS could be further divided into subcategories (e.g., degree of mental retardation, visual or hearing impairment, sports or non - sports, body composition etc.). Moreover, more trials in each condition would bring more reliable results as suggested by Pineda et al. (2020).

Limitations

The basic study limitation is the purposive, i.e. non-random selection of the participants, as well as great variability (i.e., performance diversity) in the measured values, which is, however, consistent with previous studies (Vuillerme *et al.* 2001, Villarroya *et al.* 2012, Masso *et al.* 2013, Cabeza-Ruíz *et al.* 2016).

Another possible limitation is the relatively short duration (30 s) of the PS test. Nevertheless, this duration is widely used and was confirmed as reliable by Pineda *et al*. (2020). It would also be appropriate to evaluate the PS not only by instrumental posturography, but also by functional stability tests (Malinčíková *et al.* 2011, Pastucha *et al.* 2013, Rojhani-Shirazi et. *al*., 2016, Horák *et al.* 2017).

Conclusions

The aim of this work was to assess any differences in the PS between men and women with DS. We confirmed an overall significantly lower PS of participants with DS in comparison to the reference group without DS. Furthermore, adult women with DS seem to have better PS than men, which is especially visible in the more difficult conditions. Deteriorated PS of people with DS is probably caused by a combination of the several characteristics accompanying this syndrome – muscular hypotonus, hyperlaxity of ligaments, obesity, structural changes of the cerebellum and brainstem, mental retardation. Stability disorders increase the risk of fall in these individuals with a consequence of physical activity reduction so the results of this study may be important for any professional working with people with DS.

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References

Agiovlasitis, S., Choi, P., Allred, A. T., Xu, J. and Motl, R. W. 2020. Systematic review of sedentary behaviour in people with Down syndrome across the lifespan: A clarion call. *Journal of Applied Research in Intellectual Disabilities*, *33*, 146-159.

Agiovlasitis, S., McCubbin, J. A., Yun, J., Widrick, J. J. and Pavol, M. J. 2015. Gait characteristics of adults with Down syndrome explain their greater metabolic rate during walking. *Gait & Posture*, 41, 180-184.

Antonarakis, S.E., Skotko, B.G., Rafii, M.S., Strydom, A., Pape, S.E., Bianchi, D.W., Sherman, S.L., Reeves, R.H. 2020. Down syndrome. *Nat Rev Dis Primers*, 6(1):9.

Bensmaia, S. J., Leung, Y. Y., Hsiao, S. S. and Johnson, K. O. 2005. Vibratory adaptation of cutaneous mechanoreceptive afferents. *Journal of Neurophysiology*, *94*, 3023-3036.

Bertapelli, F., Pitetti, K., Agiovlasitis, S., Guerra-Junior, G. 2016. Overweight and obesity in children and adolescents with Down syndrome-prevalence, determinants, consequences, and interventions: A literature review. *Res Dev Disabil, 57,* 181-92.

Bickley, C., Linton, J., Sullivan, E., Mitchell, K., Slota, G. and Barnes, D. 2019. Comparison of simultaneous static standing balance data on a pressure mat and force plate in typical children and in children with cerebral palsy. *Gait & Posture*, *67*, 91-98.

Bieć, E., Zima, J., Wojtowicz, D., Wojciechowska-Maszkowska, B., Kręcisz, K. and Kuczyński, M. 2014. Postural stability in young adults with Down syndrome in challenging conditions. *PLoS One*, *9*, e94247.

Blanchet, M., Prince, F., and Messier, J. 2019. Development of postural stability limits: Anteroposterior and mediolateral postural adjustment mechanisms do not follow the same maturation process. *Human Movement Science*, 63, 164-171.

Błaszczyk, J. W., Beck, M. and Sadowska, D. 2014. Assessment of postural stability in young healthy subjects based on directional features of posturographic data: vision and gender effects. *Acta Neurobiologiae Experimentalis*, *74*, 433-442.

Brenton-Rule, A., Mattock, J., Carroll, M., Dalbeth, N., Bassett, S., Menz, H. B. and Rome, K. 2012. Reliability of the TekScan MatScan® system for the measurement of postural stability in older people with rheumatoid arthritis. *Journal of Foot and Ankle Research*, *5*, 1-7.

Bull, M.J. 2020. Down Syndrome. *New England Journal of Medicine*. *382*, 2344–2352.

Cabeza-Ruiz, R., Castro-Lemus, N., Centeno-Prada, R. A. and Beas-Jiménez, J. D. 2016. Center of pressure displacements in individuals with Down syndrome during a bipedal position. *Revista Andaluza de Medicina del Deporte*, 9(2), 62-66.

Cabeza-Ruiz, R., García-Massó, X., Centeno-Prada, R. A., Beas-Jiménez, J. D., Colado, J. C., and González, L. M. 2011. Time and frequency analysis of the static balance in young adults with Down syndrome. *Gait & Posture*, *33*, 23-28.

Capio, C. M., Mak, T. C. T., Tse, M. A. and Masters, R. S. W. 2018. Fundamental movement skills and balance of children with Down syndrome. *Journal of Intellectual Disability Research*, *62*, 225-236.

Cibulková, N., Daďová, K., Mašková, K., Busch, A., Kobesová, A., Vařeková, J. and Matoulek, M. 2022. Bariatric surgery and exercise: A pilot study on postural stability in obese individuals. *PLoS One*, *17*, e0262651.

Cimolin, V., Galli, M., Grugni, G., Vismara, L., Precilios, H., Albertini, G. and Capodaglio, P. 2011. Postural strategies in Prader–Willi and Down syndrome patients. *Research in Developmental Disabilities*, *32*, 669-673.

Crawford, D. and Dearmun, A. 2016. Down's syndrome. *Nursing Children and Young People*, 28, 17-17.

de Graaf, G., Buckley, F. and Skotko, B. G. 2021. Estimation of the number of people with Down syndrome in Europe. *European Journal of Human Genetics*, *29*, 402–410.

Doyle, L., Saunders, K. J. and Little, J. A. 2016. Trying to see, failing to focus: near visual impairment in Down syndrome. *Scientific Reports*, *6*, 1-10.

Eckdahl, T. T. 2017. *Down syndrome: One smart cookie*. New York, NY: Momentum Press.

Era, P., Sainio, P., Koskinen, S., Haavisto, P., Vaara, M. and Aromaa, A. 2006. Postural balance in a random sample of 7,979 subjects aged 30 years and over. *Gerontology*, *52*, 204-213.

Evans-Martin, F. F. 2009. *Down syndrome*. New York, NY: Infobase Publishing.

Fergus, K. 2021. Symptoms of Down syndrome. *Verywell Health*. [online] Available at <https://www.verywellhealth.com/symptoms-of-down-syndrome-1120463> [Accessed 9 May 2022].

Foley, C. and Killeen, O. G. 2019. Musculoskeletal anomalies in children with Down syndrome: an observational study. *Archives of Disease in Childhood*, 104, 482-487.

Galli, M., Rigoldi, C., Brunner, R., Virji-Babul, N. and Giorgio, A. 2008a. Joint stiffness and gait pattern evaluation in children with Down syndrome. *Gait & Posture*, *28*, 502-506.

Galli, M., Rigoldi, C., Mainardi, L., Tenore, N., Onorati, P. and Albertini, G. 2008b. Postural control in patients with Down syndrome. *Disability and Rehabilitation*, *30*, 1274-1278.

Goetschius, J., Feger, M. A., Hertel, J. and Hart, J. M. 2018. Validating center-of-pressure balance measurements using the MatScan® pressure mat. *Journal of Sport Rehabilitation*, *27*.

Gomes, M. M. and Barela, J. A. 2007. Postural control in Down syndrome: the use of somatosensory and visual information to attenuate body sway. *Motor Control*, *11*, 224-234.

Gorjan, D., Šarabon, N., Babič, J. 2022. Inter-Individual Variability in Postural Control During External Center of Mass Stabilization. *Frontiers in Physiology*, 3, 12.

Guzmán-Muñoz, E. E., Gutiérrez-Navarro, L. B. and Miranda-Díaz, S. E. 2017. Postural control in children, adolescents and adults with Down syndrome. *International Medical Review on Down Syndrome*, *21*, 12-16.

Hageman, P. A., Leibowitz, J. M. and Blanke, D. 1995. Age and gender effects on postural control measures. *Archives of Physical Medicine and Rehabilitation*, *76*, 961-965.

Hertel, J., Olmsted-Kramer, L. and Challis, J. 2006. Time-to-Boundary Measures of Postural Control during Single Leg Quiet Standing. *Journal of applied biomechanics*, 22, 67-73.

Horák, S., Sovová, E., Pastucha, D., Konečný, P., Radová, L., Calabová, N. and Janout, V. 2017. Comprehensive group therapy of obesity and its impact on selected anthropometric and postural parameters. *Central European Journal of Public Health*, *25*, 326-331.

Horvat, M., Croce, R. and Fallaize, A. 2016. Information processing and motor control in Down syndrome. *Journal of Down Syndrome and Chromosome Abnormalities*, 2, 1-5.

Jain, P. D., Nayak, A., Karnad, S. D. and Doctor, K. N. 2022. Gross motor dysfunction and balance impairments in children and adolescents with Down syndrome: a systematic review. *Clinical and Experimental Pediatrics*, *65*, 142.

Kim, J., Kwon, Y., Eom, G. M., Jun, J. H., Lee, J. W. and Tack, G. R. 2012. Effects of vision, age and gender on structural and global posturographic features during quiet standing. *International Journal of Precision Engineering and Manufacturing*, *13*, 969-975.

Kim, K. M., Kim, J. S., Oh, J. and Lee, S. Y. 2019. Time-to-boundary analysis of postural control following acute lateral ankle sprain. *Gait & Posture*, 67, 151-153.

Lauteslager, P. E. M., Vermeer, A. and Helders, P. J. M. Disturbances in the Motor Behaviour of Children with Down´s Syndrome: The need for a theoretical framework. *Physiotherapy*. 1998, 84, 5-13.

Leite, J. C., Neves, J. C. D. J., Vitor, L. G. V. and Fujisawa, D. S. 2018. Evaluation of postural control in children and adolescents with Down Syndrome aged eight to twelve years old. *Journal of Human Growth and Development*, *28*, 50-57.

Malinčíková, J., Pastucha, D. and Beránková, J. 2011. Posturální stabilita u skupin dětí s obezitou a atletů. *Medicina Sportiva Bohemica et Slovaca*, 20, 24-30.

Masso, N. Gutierrez-Vilahú, L., Rey-Abella, F., Costa-Tutusaus, L. and Guerra-Balic, M. 2013. Analysis of Centre of Pressure in Standing Position in Young Down Syndrome. *Journal of Sport Sciences*, 24, 178-181.

Palmieri RM, Ingersoll CD, Stone MB, Krause BA. 2002. Center-of-pressure parameters used in the assessment of postural control. *Journal of Sport Rehabilitation*,11, 51-66.

Pastucha, D., Filipčíková, M. R., Horák, S., Malinčíková, M. J., Beránková, M. J., Bezdičková, R. M. and Vaverková, M. R. 2013. Porucha posturální stability u dětí s obezitou. *Interní medicína pro praxi*, *15*, 229-232.

Pau, M., Condoluci, C., Zago, M. and Galli, M. 2019. Men and women with Down syndrome exhibit different kinematic (but not spatio-temporal) gait patterns. *Journal of Intellectual Disability Research*, *63*, 64-71.

Pau, M., Galli, M., Crivellini, M., and Albertini, G. 2012. Foot–ground interaction during upright standing in children with Down syndrome. *Research in Developmental Disabilities*, *33*, 1881-1887.

Pineda, R.C., Krampe, R.T., Vanlandewijck, Y. and Van Biesen, D. 2020. Reliability of center of pressure excursion as a measure of postural control in bipedal stance of individuals with intellectual disability: A pilot study. *PLoS One,* 21, 15, 10

Quijoux, F., Nicolaï, A., Chairi, I., Bargiotas, I., Ricard, D., Yelnik, A., Oudre, L., Bertin-Hugault, F., Vidal, P.P., Vayatis, N., Buffat, S., and Audiffren, J. 2021. A review of center of pressure (COP) variables to quantify standing balance in elderly people: Algorithms and open-access code. *Physiological Reports*. 9, 22.

Rigoldi, C., Galli, M., Mainardi, L., Crivellini, M. and Albertini, G. 2011. Postural control in children, teenagers and adults with Down syndrome. *Research in Developmental Disabilities*, 32, 170-175.

Rojhani-Shirazi, Z., Azadeh Mansoriyan, S. and Hosseini, S. V. 2016. The effect of balance training on clinical balance performance in obese patients aged 20–50 years old undergoing sleeve gastrectomy. *European Surgery*, *48*, 105-109.

Roman-Liu, D. 2018. Age-related changes in the range and velocity of postural sway. *Archives of Gerontology and Geriatrics*, 77, 68-80.

Safi, K., Hutin, E., Mohammed, S., Albertsen, I. M., Delechelle, E., Amirat, Y. and Gracies, J. M. 2016. Human static postures analysis using empirical mode decomposition. In: *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 38, 3765-3768.

Salami, F., Vimercati, S. L., Rigoldi, C., Taebi, A., Albertini, G. and Galli, M. 2014. Mechanical energy assessment of adult with Down syndrome during walking with obstacle avoidance. *Research in Developmental Disabilities*, *35*, 1856-1862.

Tekscan. 2016. *Sportsat 2.0X: User Manual*. South Boston: Tekscan.

Tekscan. 2019. Pressure Mapping Technology. *Pressure Mapping, Force Measurement and Tactile Sensors.* [online] Available at <https://www.tekscan.com/products-solutions/pressure-mapping-technology>[Accessed 20 May 2022].

Usera, P. C., Foley, J. T., and Yun, J. 2005. Cross-validation of field-based assessments of body composition for individuals with Down syndrome. *Adapted Physical Activity Quarterly*, *22*, 198-206.

Uyanik, M., Bumin, G., and Kayihan, H. 2003. Comparison of different therapy approaches in children with Down syndrome. *Pediatrics International*, *45*, 68-73.

Véle, F. 1997. *Kineziologie pro klinickou praxi.* Praha: Grada.

Villarrasa-Sapiña, I., Álvarez-Pitti, J., Cabeza-Ruiz, R., Redón, P., Lurbe, E., García-Massó, X. 2018. Relationship between body composition and postural control in prepubertal overweight/obese children: A cross-sectional study. *Clin Biomech* (Bristol, Avon), 52, 1-6.

Villarroya, M. A., González-Agüero, A., Moros, T., Gómez-Trullén, E. and Casajús, J. A. 2013. Effects of whole body vibration training on balance in adolescents with and without Down syndrome. *Research in Developmental Disabilities*, *34*, 3057-3065.

Villarroya, M. A., González-Agüero, A., Moros-García, T., de la Flor Marín, M., Moreno, L. A. and Casajús, J. A. 2012. Static standing balance in adolescents with Down syndrome. *Research in Developmental Disabilities*, *33*, 1294-1300.

Vuillerme, N., Marin, L. and Debû, B. 2001. Assessment of static postural control in teenagers with Down syndrome. *Adapted Physical Activity Quarterly*, *18*, 417-433.

Wang, H. Y., Long, I. M. and Liu, M. F. 2012. Relationships between task-oriented postural control and motor ability in children and adolescents with Down syndrome. *Research in Developmental Disabilities*, *33*, 1792-1798.

Webber, A., Virji-Babul, N., Edwards, R. and Lesperance, M. 2004. Stiffness and postural stability in adults with Down syndrome. *Experimental Brain Research*, *155*, 450-458.

Wilton, G. J., Woodhouse, R., Vinuela-Navarro, V., England, R. and Woodhouse, J. M. 2021. Behavioural features of cerebral visual impairment are common in children with Down syndrome. *Frontiers in Human Neuroscience*, *15*, 673342.

Woollacott, M. H. 1986. The development of the postural and voluntary motor control systems in Down's syndrome children. *Advances in Psychology*, 31, 45-71.

Zago, M., Condoluci, C., Pau, M. and Galli, M. 2019. Sex differences in the gait kinematics of patients with Down syndrome: a preliminary report. *Journal of Rehabilitation Medicine*, *51*, 144-146.

Zago, M., Duarte, N. A. C., Grecco, L. A. C., Condoluci, C., Oliveira, C. S. and Galli, M. 2020. Gait and postural control patterns and rehabilitation in Down syndrome: a systematic review. *Journal of Physical Therapy Science*, *32*, 303-314.Zago, M., Condoluci, C., Manzia, C. M., Pili, M., Manunza, M. E. and Galli, M. 2021.

Multi-segmental postural control patterns in down syndrome. *Clinical Biomechanics*, 82, 105271.

Tables

Table 1. Demographic data of the samples

Group	**DS**		**Non-DS**	
	Male [15]	**Female** [11]	**Male** [15]	**Female** [11]
Age [years]	41.9 ± 7.8	33.7 ±7.9	42 ± 7.9	34.4 ± 9.3
Height [cm]	159 ± 6.3	152 ± 6.3	180 ± 8.6	167 ± 7.2
Weight [kg]	76.7 ± 12.4	73 ± 20.8	84.9 ± 11.5	70.7 ± 14.7
BMI [$kg.m^{-2}$]	30.5 ± 5.5	31.5 ± 7.4	25.8 ± 3.1	25.7 ± 5.3

Note: Values are expressed as means ± SD

Table 2. Comparison of PS variables between non-DS group and DS group

Condition	**Variable**	**Mean value ± SD**		**p-Value**	**B**
		Non-DS (n=26)	**DS (n=26)**		
WO	LoP COP	15.67 ± 3.08	31.12 ± 18.25	<0.001*	0.715
	Ex COP F-B	1.53 ± 0.43	2.26 ± 1.36	0.064	0.378
	Ex COP L-R	0.67 ± 0.30	1.48 ± 1.23	0.002*	0.816
	vCOP	0.53 ± 0.10	1.04 ± 0.61	<0.001*	0.716
	TTB F-B	3.91 ± 1.64	1.97 ± 1.29	<0.001*	-0.874
	TTB L-R	10.39 ± 3.27	5.74 ± 3.17	0.003*	-0.608
WC	LoP COP	23.40 ± 7.82	37.29 ± 28.24	0.004*	0.583
	Ex COP F-B	2.08 ± 0.77	2.24 ± 1.48	0.435	0.167
	Ex COP L-R	0.71 ± 0.35	1.40 ± 1,23	0.014*	0.685
	vCOP	0.78 ± 0.26	1.25 ± 0.94	0.004*	0.584
	TTB F-B	2.45 ± 1.21	1.69 ± 0.89	<0.001*	-0.780
	TTB L-R	8.06 ± 2.92	5.35 ± 2.51	0.008*	-0.577
NO	LoP COP	33.16 ± 8.89	58.33 ± 27.38	<0.001*	0.663
	Ex COP F-B	2.20 ± 0.73	2.63 ± 1.06	0.386	0.135
	Ex COP L-R	2.26 ± 0.58	3.16 ± 1.41	0.020*	0.345
	vCOP	1.11 ± 0.30	1.95 ± 0.92	<0.001*	0.665
	TTB F-B	2.45 ± 0.88	1.38 ± 0.68	<0.001*	-0.839
	TTB L-R	1.62 ± 0.50	1.24 ± 0.65	0.211	-0.235

Note: * = statistically significant result ($p \leq 0.05$); DS – individuals with DS, non-DS – individuals without DS; WO – wide stance with open eyes, WC – wide stance with closed eyes; NO – narrow stance with open eyes; B – unstandardized regression coefficient

Table 3. Comparison of PS variables between conditions of open and closed eyes in wide stance according to groups

	Variable	Median (IQR)		p-Value
		WO	**WC**	
Non-DS	LoP COP	14.93 (5.23)	21.14 (8.77)	<0.001*
	Ex COP F-B	1.55 (0.58)	2.09 (1.38)	0.003*
	Ex COP L-R	0.65 (0.36)	0.67 (0.34)	0.599
	vCOP	0.50 (0.18)	0.71 (0.30)	<0.001*
	TTB F-B	3.28 (2.59)	2.20 (1.65)	<0.001*
	TTB L-R	9.79 (4.24)	8.30 (3.26)	0.012*
DS	LoP COP	23.76 (20.59)	27.20 (15.03)	0.082
	Ex COP F-B	1.94 (1.39)	1.79 (1.59)	0.576
	Ex COP L-R	1.09 (0.90)	0.95 (1.10)	0.416
	vCOP	0.80 (0.69)	0.91 (0.50)	0.082
	TTB F-B	1.77 (1.58)	1.60 (1.23)	0.248
	TTB L-R	4.73 (4.47)	5.52 (3.75)	0.970

Note: Values are expressed as median (interquartile range); * = statistically significant result ($p \leq 0.05$), DS – individuals with DS, non-DS – individuals without DS, WO – wide stance with open eyes, WC – wide stance with closed eyes

Table 4. Comparison of PS variables between men and women in DS group

Condition	**Variable**	**DS group**			
		Males n = 15	**Females n = 11**	**p-Value**	**B**
WO	LoP COP	34.96 ± 17.83	25.90 ± 18.32	0.113	0.378
	Ex COP F-B	2.61 ± 1.32	1.78 ± 1.31	0.176	0.358
	Ex COP L-R	1.63 ± 1.14	1.26 ± 1.37	0.301	0.332
	vCOP	1.17 ± 0.60	0.87 ± 0.61	0.112	0.378
	TTB F-B	1.58 ± 0.87	2.48 ± 1.62	0.262	-0.300
	TTB L-R	4.97 ± 2.36	6.77 ± 3.91	0.058	-0.494
WC	LoP COP	45.34 ± 34.71	26.31 ± 8.83	0.020*	0.540
	Ex COP F-B	2.70 ± 1.70	1.61 ± 0.79	0.072	0.404
	Ex COP L-R	1.73 ± 1,43	0.96 ± 0.73	0.072	0.564
	vCOP	1.52 ± 1.16	0.88 ± 0.30	0.021*	0.539
	TTB F-B	1.48 ± 0.72	1.96 ± 1.03	0.738	-0.084
	TTB L-R	5.52 ± 2.95	5.12 ± 1.87	0.873	0.041
NO	LoP COP	63.86 ± 32.86	50.80 ± 15.94	0.160	0.287
	Ex COP F-B	2.87 ± 1.23	2.30 ± 0.69	0.025*	0.360
	Ex COP L-R	3.64 ± 1.61	2.50 ± 0.70	0.033*	0.389
	vCOP	2.13 ± 1.10	1.70 ± 0.53	0.171	0.282
	TTB F-B	1.29 ± 0.75	1.50 ± 0.59	0.478	-0.162
	TTB L-R	1.14 ± 0.54	1.36 ± 0.78	0.124	-0.355

Note: * = statistically significant result ($p < 0.05$), B – unstandardized regression coefficient; WO – wide stance with open eyes, WC – wide stance with closed eyes; NO – narrow stance with open eyes

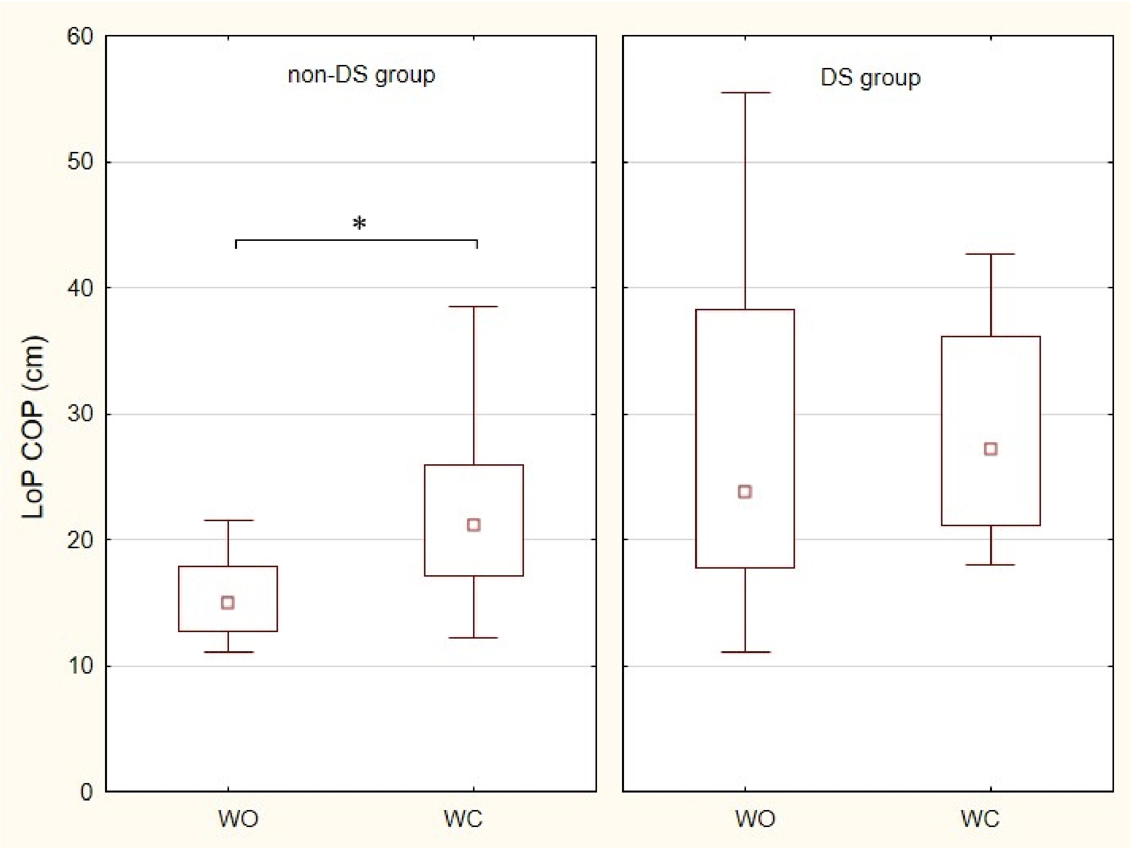

Figure 1. Difference in Length of COP Path between conditions (WO vs. WC) in non-DS and DS group displayed as median, IQR and non-outlier range

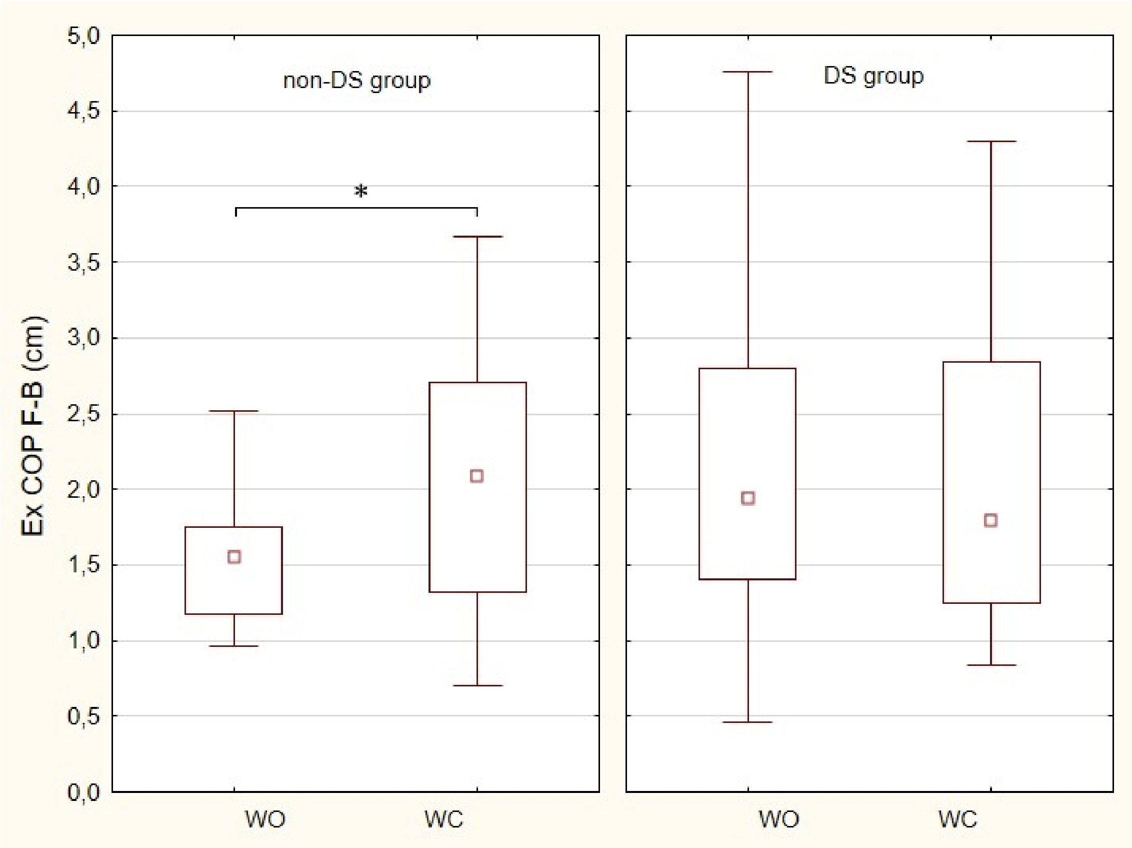

Figure 2. Difference in anterioposterior COP Excursion between conditions (WO vs. WC) in non-DS and DS group displayed as median, IQR and non-outlier range

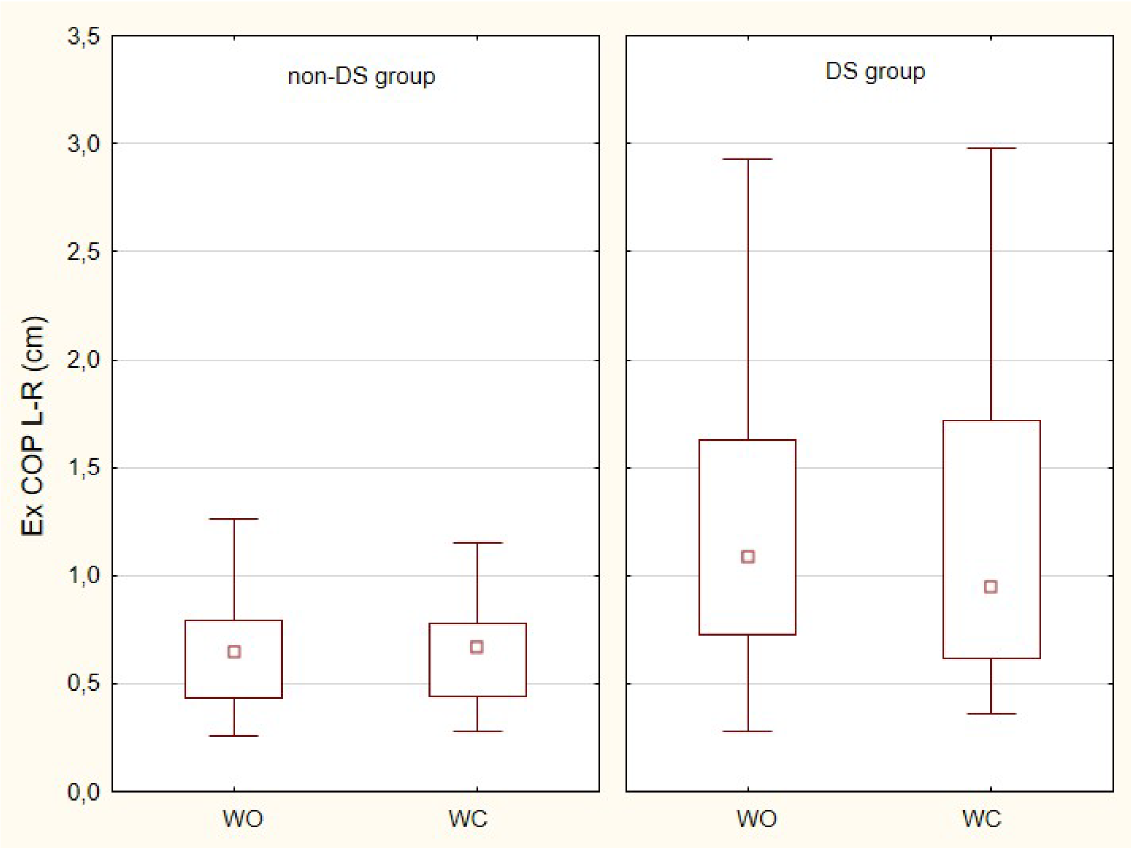

Figure 3. Difference in laterolateral COP Excursion between conditions (WO vs. WC) in non-DS and DS group displayed as median, IQR and non-outlier range

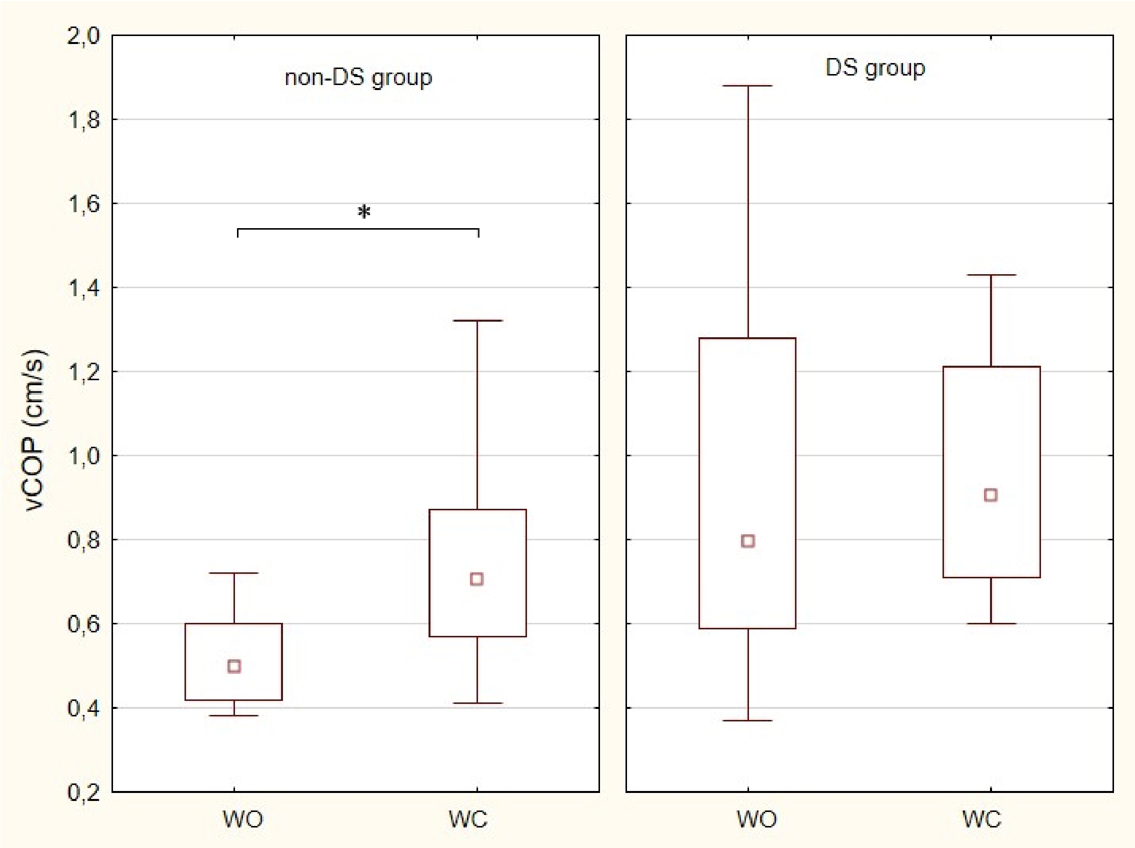

Figure 4. Difference in average rate of change of COP position between conditions (WO vs. WC) in non-DS and DS group displayed as median, IQR and non-outlier range

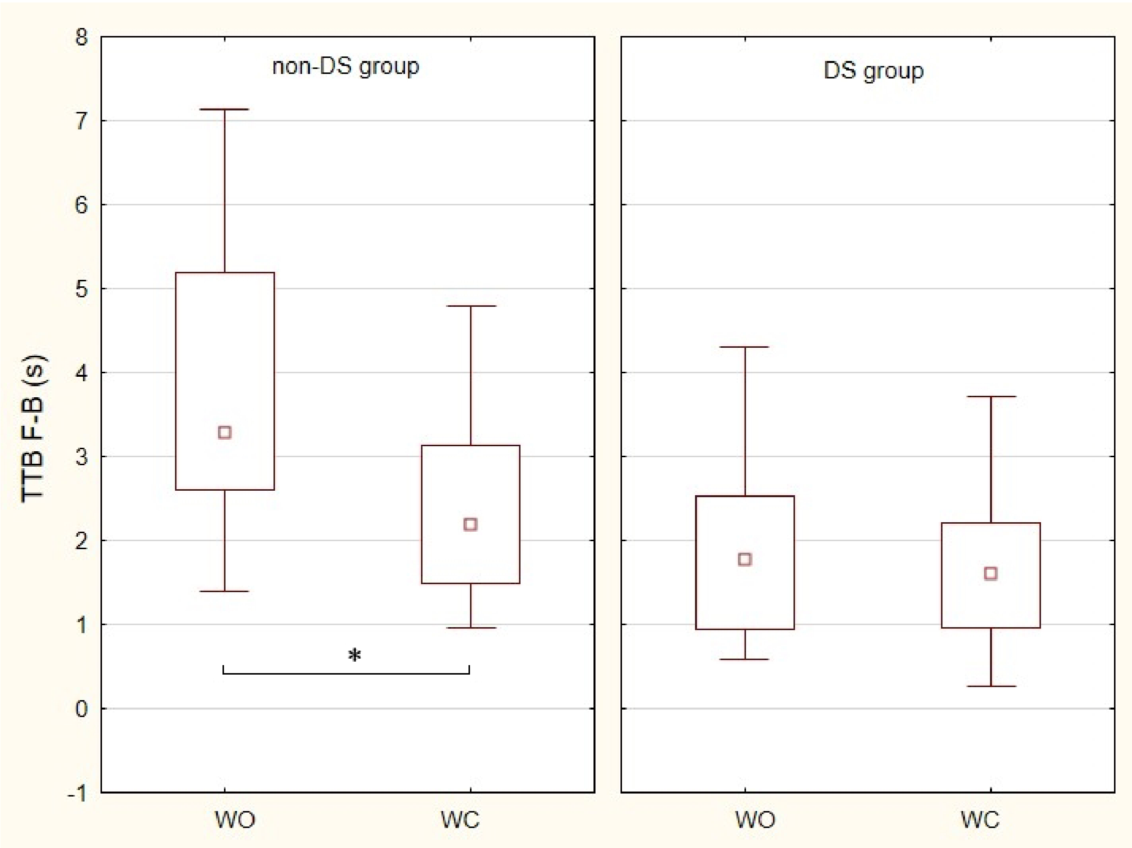

Figure 5. Difference in Time to Boundary in the anteroposterior direction between conditions (WO vs. WC) in non-DS and DS group displayed as median, IQR and non-outlier range

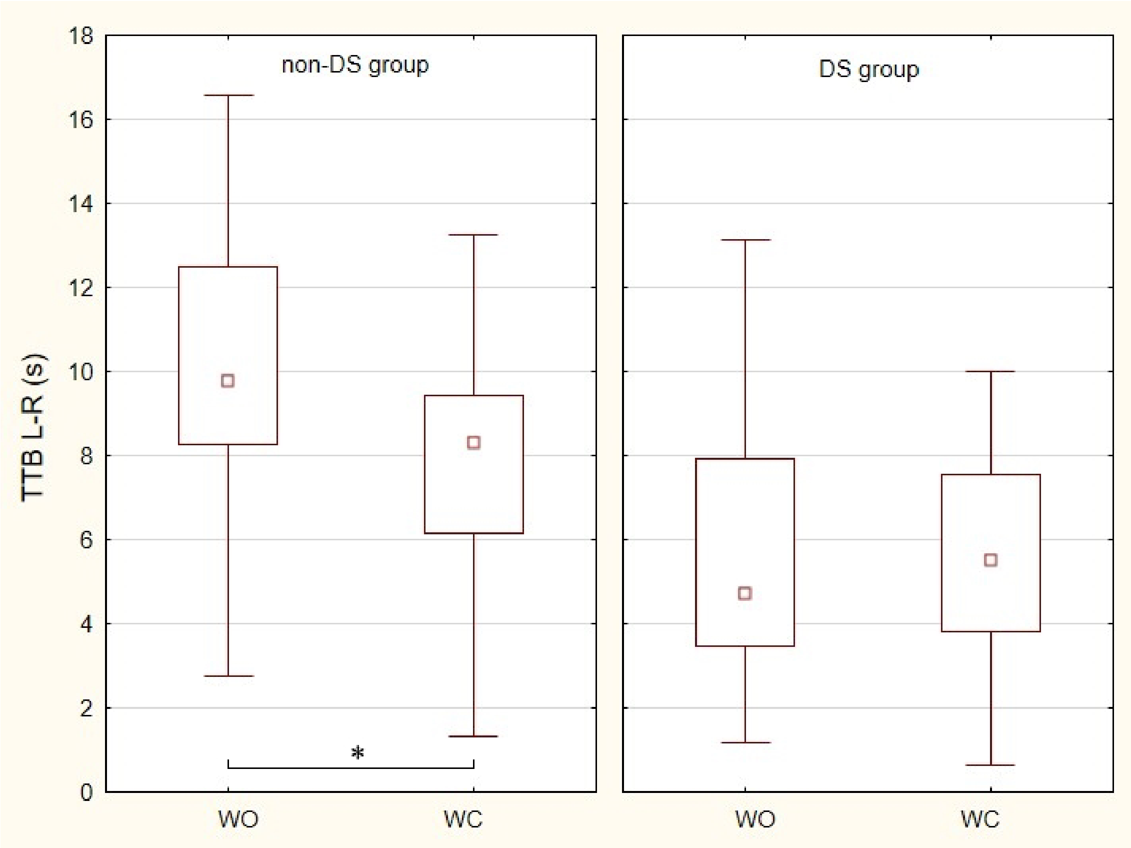

Figure 6. Difference in Time to Boundary in the laterolateral direction between conditions (WO vs. WC) in non-DS and DS group displayed as median, IQR and non-outlier range