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► To cite this version:

Jonathan Pierret, Sébastien Caudron, Jean Paysant, Christian Beyaert. Impaired postural control of axial segments in children with cerebral palsy. *Gait & Posture*, 2021, 86, pp.266-272. 10.1016/j.gaitpost.2021.03.012 . hal-03355053

HAL Id: hal-03355053

<https://hal.univ-grenoble-alpes.fr/hal-03355053>

Submitted on 24 Apr 2023

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Impaired postural control of axial segments in children with cerebral palsy

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Acknowledgements: This work was funded by the Fondation de l'Avenir (grant # AP-RMA-2015-033) and the Fondation Paralysie Cérébrale (grant # 2015-6). The authors also thank the Institut Régional de Réadaptation – Nancy (UGECAM du Nord-Est) for institutional support and Dr David Fraser (Biotech Communication SARL, Ploudalmézeau, France) for copy-editing assistance.

1 **Abstract**

2 **Background**

3 Postural control of axial segments, which develops during childhood and is not mature until
4 adolescence, is essential for the development of **the postural control during motor activities**.
5 Children with cerebral palsy (CP) have deficits in postural control when standing or walking,
6 including less stabilization of the head and trunk which could affect postural control.

7 **Research question**

8 **Is dynamic stabilization of axial segments during an unstable sitting task deficient in children**
9 **with CP compared to typically developing children? Is this deficit correlated with the deficit**
10 **of postural control during standing?**

11 **Method**

12 Seventeen children with CP (GMFCS I-II) and 17 typically-developing children from 6 to 12
13 years old were rated on the Trunk Control Measurement Scale (TCMS) and had
14 posturographies **during standing, sitting and unstable sitting**. In the latter, participants had to
15 maintain balance during stable sitting, unstable sitting and quiet standing in “eyes open” and
16 “eyes closed” conditions. In sitting tasks, the participants had to remain stable while being
17 prevented from using the lower and upper limbs (i.e. to ensure the involvement of axial
18 segments alone).

19 **Results**

20 The CP and TD groups differed significantly with **higher values of** the area, mean velocity
21 and RMS of CoP displacements measured during the unstable sitting task and the standing
22 task, under both “eyes open” and “eyes closed” conditions. No significant group effects were
23 observed during the stable sitting task. The TCMS total score was significantly lower,
24 indicating trunk postural deficit, in the CP group than in the TD group and was significantly
25 correlated with postural variables in the sitting and standing tasks.

1 **Significance**

2 Children with CP indeed have a specific impairment in the postural control of axial segments.

3 Since the postural control of axial segments is important for standing and walking, its

4 impairment should be taken into account in rehabilitation programs for children with CP.

5

6 **Keywords**

7 Cerebral palsy, postural control, axial segments, unstable sitting, postural development

8

1 **Abbreviations**

2 ANOVA: analysis of variance

3 CP: cerebral palsy

4 CoP: center of pressure

5 DR: dynamic reaching

6 EC: eyes closed

7 EO: eyes open

8 GMFCS: Gross Motor Function Classification System

9 RMS: root mean square

10 SMC: selective movement control

11 SSB: static sitting balance

12 TCMS: Trunk Control Measurement Scale

13 TD: typically developing

1 **1. Introduction**

2 From early childhood onwards, children with cerebral palsy (CP) exhibit impairments in
3 postural control in static and dynamic situations, even after they are able to stand and walk on
4 their own [1,2]. Indeed, their postural control is impaired during quiet standing under various
5 sensory conditions [2,3], with greater center of pressure (CoP) sway than in typically
6 developing (TD) children, **indicating less accurate and efficient postural control compared to**
7 **TD children**. Children with CP have specific difficulty in resolving intersensory conflicts
8 when standing, and appear to be more affected when somatosensory information is disrupted
9 [2]. With regard to the effect of vision on posture, most previous studies found that children
10 with CP swayed more in an “eyes closed” (EC) condition than in an “eyes open” (EO)
11 condition [1,3] – as did TD children, whereas a few studies did not evidence any difference
12 between the two conditions [4].

13 Children with CP from early childhood (2 years old) until adolescence (~ 15 years old) also
14 exhibit abnormal postural reactions to external disturbances consisting of sudden translations
15 of the support, with different muscle recruitment while sitting [5] or standing [6]. Specifically,
16 children with CP show a **proximal to distal** muscle recruitment pattern, rather than the normal
17 **distal to proximal** pattern; this **proximal to distal muscle recruitment** pattern is associated with
18 highly variable muscle responses, long activation latencies, antagonistic co-contractions, and
19 poor adaptation to the intensity of the disturbance [6,7]. Since the alterations in balance
20 recovery after an external perturbation are similar when sitting or standing, it could be
21 suggested that the postural control of axial segments contributes significantly to these postural
22 impairments [6,7]. In the sitting position, children with CP notably have difficulty keeping
23 their head stable, and sway more than TD children [8,9]. When walking, children with CP
24 have larger ranges of head and trunk motion in each plane [10–12]. Given that the trunk is the
25 primary reference frame for postural control [13], the development of postural and kinetic

1 activities (such as locomotion and the acquisition of gross motor skills) is also likely to be
2 altered by impaired control of axial segments [13].

3 We therefore reasoned that evaluating ability to stabilize axial segments may be of value for
4 the therapeutic management of children with CP. Growing interest in the assessment of trunk
5 control in children with CP has prompted the development of a validated, specific clinical tool
6 - the Trunk Control Measurement Scale (TCMS) [14]. This scale provides a functional
7 evaluation of trunk control in a sitting subject during movements of the upper and lower limbs
8 (with the trunk stabilized) or during active movements of body segments (including the
9 trunk). Furthermore, a number of unstable seat devices have been recently developed [15].
10 Since the maintenance of balance on these devices requires strong postural regulation
11 specifically by the upper body they allowed the specific evaluation of postural control of the
12 trunk in various pathological populations as well as the analysis of the development of
13 postural control in TD children during middle childhood [15–17]. In particular, it has been
14 shown that although TD children are able to sit and stand independently as early as two years
15 of age, the development of axial stabilization continues between 6 and 11 years of age and is
16 not yet mature at the beginning of adolescence [17]. To the best of our knowledge, unstable
17 seat devices have not previously been used to test the postural control of axial segments in
18 children with CP during this developmental period. This approach would highlight the
19 contribution of axial segment impairments to balance disorders in children with CP.

20 The main objectives were to **determine if (i) children with CP show** a deficit in postural
21 control of axial segments in the sitting posture, using TCMS and an unstable sitting device,
22 and (ii) its correlation with a deficit of postural control in the standing posture in children with
23 CP aged from 6 to 12 compared to aged-matched TD children. In addition, visual deprivation
24 was tested in order to observe whether the deficit in postural control of axial segment is found
25 in the absence of vision and is not dependent on the use of visual information.

2. Methods

2.1 Participants

Seventeen children with CP (7 girls, 10 boys, age: $7.9 \text{ y} \pm 2.4$, height: $127 \text{ cm} \pm 15$, weight: $26.7 \text{ kg} \pm 7.5$; 11 diplegic and 6 hemiplegic) and 17 age-matched TD children (8 girls, 9 boys, age: $7.7 \text{ y} \pm 2$, height: $129 \text{ cm} \pm 15$, weight: $25.6 \text{ kg} \pm 6.8$) were included in the study.

None of the children with CP had undergone surgery to correct orthopaedic disorders in the lower limbs or axial segments and none had received botulinum toxin injections in the lower limbs in the 6 months prior to the study, and all were able to walk without walking aids [Gross Motor Function Classification System (GMFCS) level I: n=9; GMFCS level II: n=8].

The GMFCS was always assessed by CB whom is an experienced pediatrician, after interviewing the parent(s) and the child [18]. None of the TD children had a history of neurologic or musculoskeletal disorders. All the children had a sufficient level of understanding and cooperation to perform the tasks. The experimental protocol complied with the tenets of the Declaration of Helsinki and was approved by the local investigational review board “CPP Est-III” (France) n°2015-A000022-47/15.02.03. The participants’ parents gave their written, informed consent to their child’s participation in the study.

2.2 Tasks and data acquisition

The sitting postural tasks: the children were asked to sit on an unstable seat device (Fig. 1) placed on a three-dimensional force platform (AMTI, Watertown, MA, USA). A cardan joint and four springs arranged around the cardan joint allowed the seat to tilt in a frictionless manner along the mediolateral and anteroposterior axes, with a maximum lowering of 3cm of the seat edges (tilt of 12°) to avoid any risk of falling of seated participant. The participant was instructed to remain as still as possible while sitting in an upright position with the arms crossed on the chest (i.e. suppressing the upper limbs’ contribution to postural control), and

1 the feet resting on an adjustable footrest (in height and depth) integral with the unstable
2 seating device. The knee and hip joint angles were kept at 90°, and movements of the lower
3 limbs were also restricted by foam blocks strapped between and around them (i.e. suppressing
4 out the lower limbs' contribution to postural control). Hence, only the body's axial segments
5 contributed to balance on the unstable seat device. The device was either locked in a static
6 horizontal position using wooden blocks (*the stable sitting postural task*: Fig. 1C) or was left
7 unlocked (*the unstable sitting postural task*). In the latter task, we used the prior calibration
8 procedure developed by Larivière et al. (2013) (individual adjustment of the distance between
9 the pivot joint and the springs) [15] so that the task's level of difficulty was independent of
10 the participant's anthropometric characteristics.

11 *[Figure 1]*

12 *The standing postural task*: the children were required to stand on the three-dimensional force
13 platform with their arms at their sides, feet about hip width apart and to remain as still as
14 possible.

15 The sitting and standing postural tasks (each lasting 30 seconds) were carried out three times
16 under both EO and EC conditions. The order of the sitting tasks stable vs. unstable combined
17 with the EO vs. EC conditions was randomized. The participant rested for 30 seconds
18 between tasks.

19 *The Trunk Control Measurement Scale*. The TCMS is composed of three subscales all
20 completed in sitting posture: the static sitting balance (SSB) subscale (20 points) evaluates the
21 capacity to stabilize the trunk during upper and lower limb movements; the selective
22 movement control (SMC) subscale (28 points) evaluates the selective movement of the trunk
23 within the base of support; and the dynamic reaching (DR) subscale (10 points) measures the
24 ability to make reaching movements outside the base of support [14]. Each item on the scale

1 was scored three times, and the best of the three scores was recorded. The total TCMS score
2 ranged from 0 (worst performance) to 58. The TCMS was administered after postural tasks
3 after a rest period of at least 15 minutes to avoid measurement bias due to fatigue. TCMS was
4 administered by the same experienced investigator.

5 **2.3 Data recording and processing**

6 During all the postural tasks, CoP trajectories were recorded at a sampling rate of 1000 Hz.
7 Raw data were filtered with a low-pass Butterworth filter (order: 4; cut-off: 12 Hz). Next, the
8 following data were averaged over three trials: (i) the CoP area (mm²), computed from the
9 95% confidence ellipse of the CoP displacement; (ii) the CoP mean velocity (mm.s⁻¹); and
10 (iii) the root mean square (RMS) of the CoP displacements (mm). All the data processing
11 steps were performed using MATLAB R2017 software (MathWorks, Natick, MA, USA).

12 **2.4 Statistical analyses**

13 Quantitative data were reported as the mean \pm standard deviation (SD). For each postural task,
14 the three postural dependent variables were analyzed separately using a mixed-design analysis
15 of variance (ANOVA). For each variable, a 2 \times 2 two-way ANOVA was performed with
16 “group” as the between-subject factor (TD group; CP group) and “vision condition” (EO; EC)
17 as the within-subject factor. Tukey's honestly significant difference test was used for post-hoc
18 comparisons, when necessary. Size effects were reported with partial eta² statistics (η_p^2). The
19 TCMS total score and subscale scores for the CP and TD groups were compared using
20 independent Student's t-tests. Pearson's correlation coefficient was computed in each group,
21 in order to examine putative linear relationships between the TCMS scores and each of the
22 CoP variables during the sitting and standing postural tasks. The threshold for statistical
23 significance was set to $\alpha=0.05$.

24

3. Results

In children with CP, the demographic variables, postural variables, and TCMS did not differ significantly between GMFCS I and GMFCS II; therefore, the data were pooled for analysis.

3.1 The stable sitting postural task

During the stable sitting postural task, there was no main effect of group or group \times vision interaction both for CoP area, CoP mean velocity and CoP RMS. However, there was a significant main effect of vision, with higher values under EC conditions than under EO conditions (Fig 2, Table 1).

3.2 The unstable sitting postural task

One child in the CP group failed to complete this task, and so the corresponding data were excluded from this analysis. During the unstable sitting postural task, significant main effects of group and vision were observed for the three dependent variables; the values were higher in the CP group than the TD group, and higher in the EC condition than in the EO condition, respectively (Fig 2, Table 1). There was also a significant interaction between the group and the vision condition for the three variables (Table 1). More precisely, all the variables had significantly higher values in the CP group than in the TD group under both EC and EO conditions (EC condition: $p < 0.001$ for all variables, EO condition: $p < 0.001$ for CoP area, $p = 0.02$ for CoP velocity, and $p = 0.008$ for CoP RMS). For each variable, there was a significant difference between the EO and EC conditions in each group ($p < 0.001$ for each variable in the CP group; $p < 0.05$ for each variable in the TD group).

3.3 The quiet standing postural task

During the quiet standing postural task, significant main effects of group and vision were observed for the three dependent variables; the values were higher in the CP group than the

1 TD group, and higher in the EC condition than the EO condition (Fig 2, Table 2). Lastly, there
2 was no significant interaction between the group and the vision condition.

3 [Figure 2]

4
5 [Table 1]

6 7 **3.4 The TCMS scores**

8 The mean \pm SD total TCMS score was significantly lower in the CP group than the TD group
9 [36.3 \pm 6.9 vs. 53.3 \pm 3.2, respectively; $t(32) = 9.28, p < 0.001$]. The same was true for the SSB
10 subscale score [CP: 16.9 \pm 2.6; TD: 19.8 \pm 0.6; $t(32) = 4.44, p < 0.001$], the SMC subscale score
11 [CP: 12.2 \pm 4.0; TD: 23.8 \pm 2.9; $t(32) = 9.66, p < 0.001$] and the DR subscale score [CP: 7.1 \pm 1.2;
12 TD: 9.8 \pm 0.6; $t(32) = 8.42, p < 0.001$]. The total TCMS score had significant, moderate-to-
13 strong negative correlations with (i) the CoP area and CoP RMS during the unstable sitting
14 task in the CP group only and during the quiet standing task in both the CP and TD groups,
15 and (ii) the CoP velocity during the stable sitting task in the TD group although a non-
16 significant trend was observed in the CP group (Table 2).

17 [Table 2]

18 **4. Discussion**

19 Children with CP had more difficulty than TD children in stabilizing their axial segments
20 during unstable sitting and quiet standing tasks. In children with CP, the total TCMS score
21 was lower than in TD children and was negatively correlated with postural variables in both
22 the unstable sitting and quiet standing tasks. Visual deprivation was associated with decreased
23 stability in both groups and in all the sitting and standing postural tasks.

1 **4.1 Impaired postural control of axial segments in children with CP**

2 Relative to TD children, children with CP displayed impairment in the postural control of
3 axial segments in the unstable sitting task but not in the stable sitting task. In the latter task,
4 **although** the values of all the CoP variables were slightly higher in the CP group than in the
5 TD group, **there was no significant differences**. Given that a stable sitting posture is less of a
6 balance challenge than standing, the absence of an inter-group difference in this task suggests
7 that in children with CP, axial segment control was sufficiently well developed to provide a
8 stable sitting posture. Furthermore, the children with CP included in this study (GMFCS I or
9 II) had moderate impairments of gross motor function. Liao et al [8] reported that CoP sway
10 distances did not differ significantly when comparing children with CP and TD children
11 during static sitting but were significantly higher in children with CP during dynamic sitting
12 on a support tilting backward before being back to horizontal.

13 Both static and dynamic aspects of postural control of the trunk were impaired in the CP
14 group according to our present results for the three TCMS subscale scores, as previously
15 reported by Heyrman et al. [14]. Interestingly, the total TCMS score was moderately and
16 negatively correlated with both CoP area and CoP RMS during the unstable sitting task. This
17 finding shows that the unstable sitting task is a reliably challenging task that specifically
18 reveals and quantifies impairments in the postural control of axial segments. Furthermore, the
19 unstable sitting task is not based on an externally induced movement of the support; hence, it
20 contrasts with earlier reports of dynamic postural tasks involving either an expected
21 movement (such as support oscillations [8]) or an unexpected translations [5]. On the
22 contrary, the seat movements during unstable sitting are internally induced in relation to the
23 movements of the axial segments because none of the four limbs can move independently. As
24 a result, the ability to maintain balance on the unstable sitting device relies to some extent on
25 a proactive control of the posture, requiring the anticipation of axial segment oscillations that

1 will induce inclinations of the seat. This provides a possible **explanation** for the difficulty of
2 children with CP to stabilize themselves during the dynamic tasks. In TD children, the
3 improvement in postural control is partially explained by a **slight** improvement in proactive
4 control with age [19], which is based on the progressive construction of internal model of
5 action [20]. In children with CP, proactive control is disrupted specifically in the trunk
6 musculature [21]. In addition, the development of internal models of action, necessary to
7 establish proactive control, is also disrupted [22,23].

8 Furthermore, the self-balancing task becomes even more difficult when the seat angle is high,
9 due to poor stabilization of the axial segments. The corresponding increase in balance
10 disturbance therefore prompts further postural reactions with muscle activations to restore
11 balance. It has been shown that in children with CP, neuromuscular disorders cause postural
12 reactions that differ from those observed in TD children [5,7]. In addition, exaggerated
13 stretching reflexes potentially triggered in the postural muscles when the seat is tilted, high
14 muscle tone and muscle weakness may accentuate the difficulties that children with CP have
15 in balancing on the unstable sitting device [7]. Muscle weakness seems to be a convincing
16 explanation. Indeed, while the thighs are immobilized on the unstable sitting device, hip
17 muscles such as the gluteus maximus and gluteus medius, which exert a force on the pelvis
18 and indirectly on the seat, may contribute to the sitting posture and its stability [24] The
19 muscle weakness of the gluteus maximus and medius observed in children with cerebral palsy
20 [25,26] may then contribute to their reduced postural stability on the unstable sitting device
21 compared to TD children.

22 Impaired postural control of axial segments may be a key target for rehabilitation in children
23 with CP. Enhanced axial rehabilitation, based on a variety of exercises in intermediate
24 postures that strongly involve the trunk to cope with balance, may be of great interest if it
25 affects the standing postural control [27].

1 **4.2 Does the impaired control of the trunk affect the standing postural control in CP** 2 **children?**

3 The total TCMS score is negatively correlated with both CoP Area and RMS in CP and TD
4 children. Thus, a lower TCMS score is associated with larger postural sways during the quiet
5 standing task. The trunk, which accounts for about 60% of body mass in children [28] and
6 thus contributes to the elevated position of the body's center of mass in the standing position,
7 plays a crucial role in postural control [29]. Indeed, even small deviations of the trunk have a
8 strong impact on the CoP displacements. It is worth noting that TD children in middle
9 childhood develop in parallel their ability to stabilize themselves on an unstable sitting device
10 involving only the axial segments [17] as well as during quiet standing [30]. The fact that
11 postural sways during quiet standing do not decrease with age in children with CP [1] may be
12 related to delayed postural development [31] which also affects control of the axial segments.
13 A longitudinal study of axial stabilization in children with CP would be required to confirm
14 this hypothesis. In addition, in children with CP, the deficit in trunk postural control in
15 dynamic activities, as evidenced by the low scores on the SMC and DR subscales of the
16 TCMS, may influence other dynamic activities such as walking, in which larger trunk
17 deviations have been described in children with CP [10–12].

18 **4.3 The effect of visual deprivation on postural control is more pronounced in CP** 19 **children when the task is difficult**

20 As already reported elsewhere [1,3], visual deprivation was associated with higher values of
21 all the CoP variables in all tasks and in both groups. This finding underlines the importance of
22 visual feedback for postural control, as extensively highlighted in the literature. The
23 interaction observed between vision and group in the unstable sitting task suggests that when
24 the postural challenge was accentuated (by either increasing the level of difficulty or
25 modifying the sensory context), the difference between CP and TD children in the control

1 capacity of axial segments increased. Earlier research has suggested that children with CP
2 have an impairment in the organization of sensory inputs; this would probably lead to
3 difficulties when inputs are disrupted during task performance, in particular when the support
4 is unstable and vision is absent [2]. Although the unstable seat task assessed in the present
5 study did not involve sensory disturbance *per se*, reliance solely on somatosensory and
6 vestibular information prevented children with CP from balancing as effectively as TD
7 children. It should be noted, however, that during the stable sitting task the difference between
8 the mean values of the CoP variables in the EO and the EC condition, although significant, is
9 relatively small (especially for the CoP velocity) and therefore may not be clinically relevant.

10 **4.4 Study limitations**

11 We found no significant differences in postural variables and TCMS between children with
12 CP at the GMFCS I and GMFCS II levels. It has also been reported that conventional
13 posturography in quiet standing, as we did, did not differ between children with GMFCS I and
14 GMFCS II [32]. However, the dynamic structure of CoP trajectories in quiet standing [32]
15 and the functional reach test, a method of testing dynamic standing balance, can distinguish
16 between children with GMFCS I and II [33]. One would expect that dynamic postural control
17 of axial segments, as evaluated by the unstable sitting postural task and TCMS, would be
18 different in children with GMFCS I and GMFCS II. The limited number of subjects in each
19 GMFCS level does not allow us to conclude on this point. In addition, the limited number of
20 subjects did not allow the data to be analyzed according to the affected topography
21 (hemiplegic or diplegic) of children with CP. However, this factor may affect the severity of
22 axial control disorders. Gluteal and trunk muscle activities would also have been informative
23 to record, particularly to better differentiate between the feedforward and feedback
24 mechanisms of trunk control. Dynamic stabilization on the unstable sitting device could be
25 influenced by a learning effect: this effect was reduced by randomizing the conditions (stable

1 and unstable, eyes open and eyes closed). Lastly, the randomization between the different
2 tasks could have been improved if TCMS had been included in this randomization. However,
3 for practical reasons, the TCMS was performed after the postural tasks.

4 **5. Conclusion**

5 To the best of our knowledge, the present study is the first to have used an unstable seat
6 device in a dynamic postural task that specifically highlighted the impairment of axial
7 segment postural control in children with CP. This impaired ability to self-stabilize by using
8 axial segments was correlated with a more general impairment in trunk control under various
9 static and dynamic conditions, as evidenced by the TCMS score. Since axial segments have
10 an important role in motor activities such as standing, we suggest that the impaired postural
11 control of axial segments is likely to contribute to the self-stabilizing difficulties observed
12 among children with CP in quiet standing. Since the postural control of axial segments is
13 important for standing and walking, its impairment should be taken into account in
14 rehabilitation programs for children with CP. Visual deprivation nonspecifically altered
15 stability in all postural tasks in both groups, and specifically altered stability more in the CP
16 group than in the TD group in the unstable sitting task.

17

18

19 **Declarations of interest:** none

20

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1 **Figure captions**

2 **Figure 1.** (A) A side view of the unstable seat device's cardan joint. (B) A view of the underside of the seat,
3 showing the cardan joint and the four springs. The difficulty of the postural task can be homogenized as a
4 function of the participant's anthropometric characteristics by changing the distance between the spring and the
5 cardan joint; the greater the distance, the more stable the seat. (C) Sagittal and (D) frontal views of the unstable
6 seat device.

7 **Figure 2.** Mean confidence ellipse area (in mm²), CoP velocity (in mm.s⁻¹) and CoP RMS (mm) recorded during
8 the stable sitting postural task, the unstable sitting postural task, and the standing postural task in the TD group
9 (dark bars) and the CP group (grey bars) and under eyes-open (EO) and eyes-closed (EC) conditions. The error
10 bars correspond to 1 SD. The symbol † indicates a significant difference between EO and EC (††† p < 0.001),
11 and the symbol ‡ indicates a significant difference between the TD and CP groups (‡‡‡ p < 0.001). The asterisk
12 indicates significant post-hoc test result for the vision x group interaction (*p < 0.05; **p < 0.01; ***p < 0.001)
13 – notably the difference between EO and EC conditions within a group, and an intergroup difference within a
14 condition.

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1 **Table 1**

2 **Table 1:** Summary of statistical results concerning the ANOVA performed on the three CoP variables (Area,
 3 mean velocity and RMS) during each postural task (stable sitting, unstable sitting, quiet standing). Main Group
 4 effect and vision effect and group \times vision interaction are reported with F , p and η^2 values.

| Postural task | Postural variable | Group | | | Vision condition | | | Group \times vision interaction | | |
|------------------|-------------------|---------------------|-------|----------|---------------------|-------|----------|-----------------------------------|-----|----------|
| | | F Value | p | η^2 | F Value | p | η^2 | F Value | p | η^2 |
| Stable sitting | CoP Area | $F_{(1,32)} = 2.81$ | .10 | | $F_{(1,32)} = 41.0$ | <.001 | .56 | $F_{(1,32)} = 0.13$ | .71 | |
| | CoP Velocity | $F_{(1,32)} = 0.10$ | .74 | | $F_{(1,32)} = 10.5$ | <.01 | .24 | $F_{(1,32)} = 0.56$ | .45 | |
| | CoP RMS | $F_{(1,32)} = 0.8$ | .37 | | $F_{(1,32)} = 37.9$ | <.001 | .54 | $F_{(1,32)} = 0.03$ | .85 | |
| Unstable sitting | CoP Area | $F_{(1,31)} = 79.4$ | <.001 | .71 | $F_{(1,31)} = 41.7$ | <.001 | .71 | $F_{(1,31)} = 5.10$ | .03 | .14 |
| | CoP Velocity | $F_{(1,31)} = 20.9$ | <.001 | .40 | $F_{(1,31)} = 34.2$ | <.001 | .52 | $F_{(1,31)} = 4.17$ | .04 | .11 |
| | CoP RMS | $F_{(1,31)} = 22.2$ | <.001 | .41 | $F_{(1,31)} = 39.1$ | <.001 | .55 | $F_{(1,31)} = 4.98$ | .03 | .13 |
| Quiet standing | CoP Area | $F_{(1,32)} = 58.4$ | <.001 | .64 | $F_{(1,32)} = 21.2$ | <.001 | .39 | $F_{(1,32)} = 1.40$ | .24 | |
| | CoP Velocity | $F_{(1,32)} = 15.7$ | <.001 | .32 | $F_{(1,32)} = 6.95$ | <.01 | .17 | $F_{(1,32)} = 0.51$ | .47 | |
| | CoP RMS | $F_{(1,32)} = 46.4$ | <.001 | .59 | $F_{(1,32)} = 16.5$ | <.001 | .33 | $F_{(1,32)} = 2.60$ | .11 | |

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1 **Table 2**

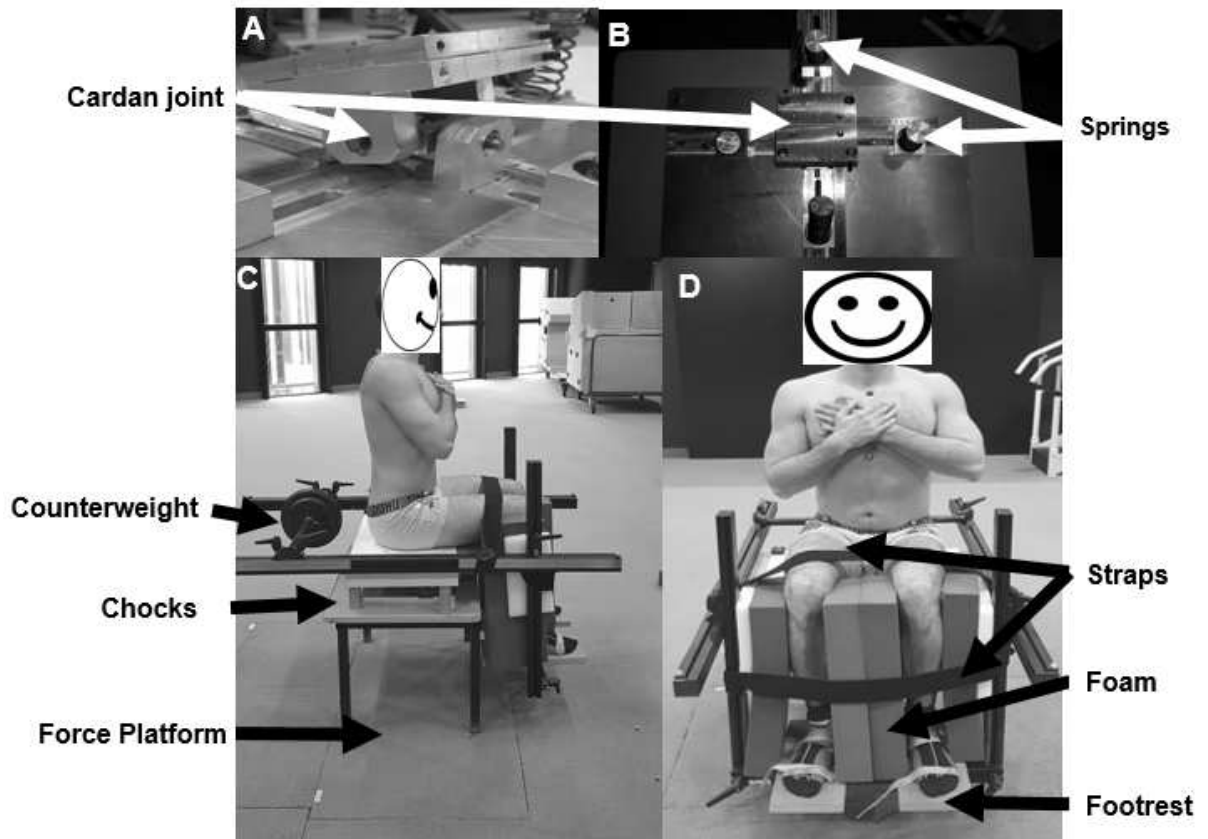
2 **Table 2:** Pearson's r for the correlations between the total TCMS score and the dependent postural variables.

| Postural task | Postural variable | TD group | CP group |
|------------------|-------------------|--------------------|--------------------|
| Stable sitting | CoP area | -0.26 | -0.2 |
| | CoP velocity | -0.53* | -0.43 ^t |
| | CoP RMS | -0.26 | -0.1 |
| Unstable sitting | CoP area | 0.13 | -0.52* |
| | CoP velocity | 0.15 | -0.20 |
| | CoP RMS | 0.13 | -0.52* |
| Quiet standing | CoP area | -0.63** | -0.68** |
| | CoP velocity | -0.45 ^t | -0.2 |
| | CoP RMS | -0.63** | -0.68** |

3 * $p < 0.05$; ** $p < 0.01$; t indicates a trend ($p = 0.05$ to 0.08).

4

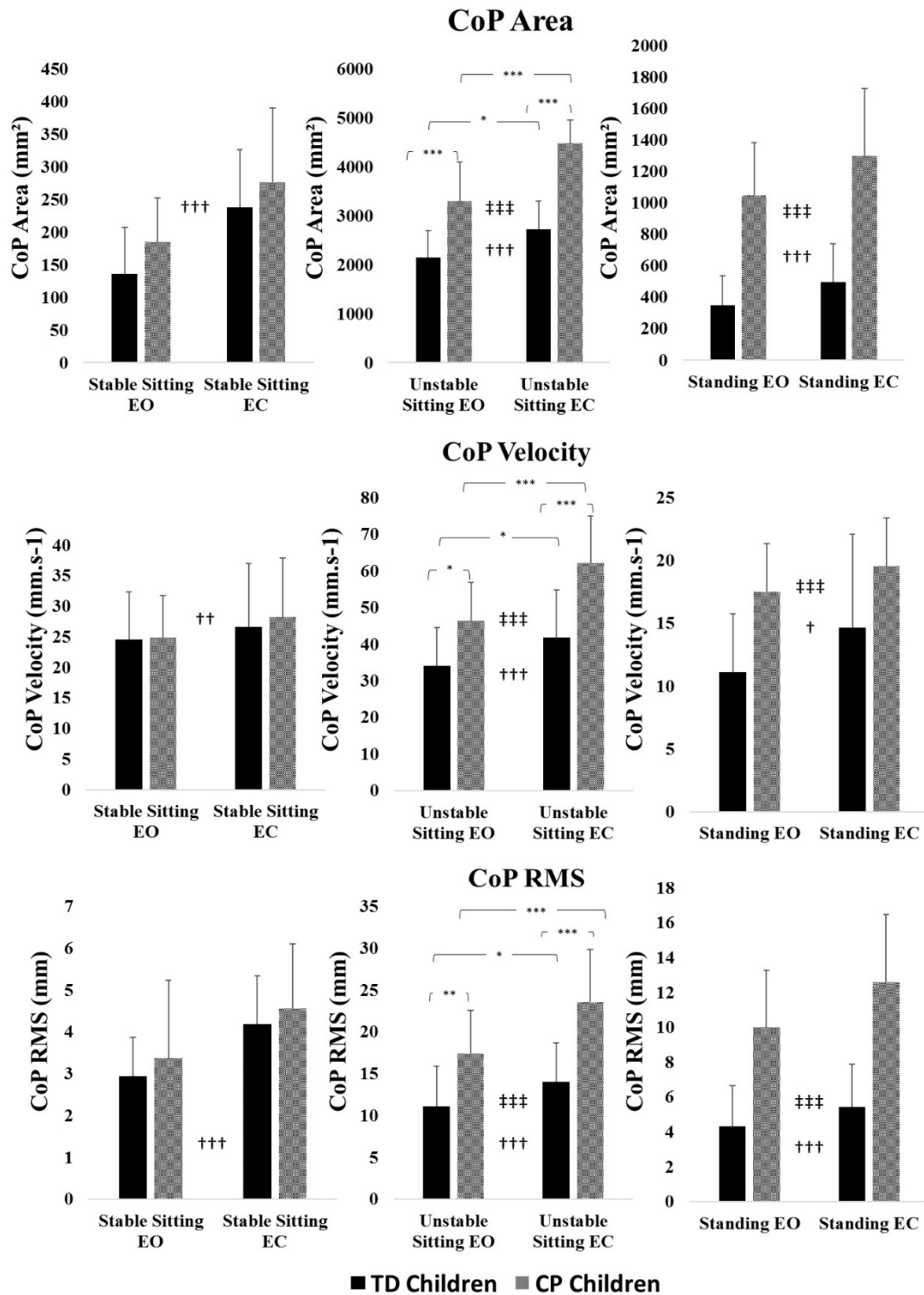
1 **Figure 1**



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1 **Figure 2**



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