



## Effects of dual tasking on postural and gait performances in children with cerebral palsy and healthy children

Estelle Palluel, Guillaume Chauvel, Véronique Bourg, Marie-Christine Commare, Chloé Prado, Vincent Farigoule, Vincent Nougier, Isabelle Olivier

### ► To cite this version:

Estelle Palluel, Guillaume Chauvel, Véronique Bourg, Marie-Christine Commare, Chloé Prado, et al.. Effects of dual tasking on postural and gait performances in children with cerebral palsy and healthy children. International Journal of Developmental Neuroscience, 2019, 79 (1), pp.54-64. 10.1016/j.ijdevneu.2019.10.008 . hal-03216921

**HAL Id: hal-03216921**

**<https://hal.science/hal-03216921>**

Submitted on 4 May 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Running Head: Dual tasking in CP and healthy children

Effects of dual tasking on postural and gait performances in children with cerebral palsy and healthy children

Estelle Palluel<sup>1</sup>

Guillaume Chauvel<sup>2</sup>

Véronique Bourg<sup>3</sup>

Marie-Christine Commare<sup>3</sup>

Chloé Prado<sup>3</sup>

Vincent Farigoule<sup>3</sup>

Vincent Nougier<sup>1</sup>

Isabelle Olivier<sup>1</sup>

<sup>1</sup> Univ. Grenoble Alpes, CNRS, TIMC-IMAG, F-38000 Grenoble, France

<sup>2</sup> Univ. Paris Est Creteil, LIRTES, 94009 Creteil cedex, France

<sup>3</sup> Department of Physical Medicine and Readaptation, University Hospital Grenoble-Alpes,

University Grenoble-Alpes, France

Corresponding Author: Estelle Palluel

Laboratoire TIMC–Faculté de médecine–Bât Jean Roget

Université Grenoble Alpes

38 706 La Tronche Cedex, France

[estelle.palluel@univ-grenoble-alpes.fr](mailto:estelle.palluel@univ-grenoble-alpes.fr)

## Abstract

Simultaneous execution of motor and cognitive tasks is embedded in the daily life of children. 53 children of 7–12 years and 22 adults (study 1), 20 healthy children and 20 children of 7-12 years with cerebral palsy (study 2) performed a Stroop-animal task simultaneously with a standing or a walking task in order to determine the attentional demand of postural control and locomotion. Dual-task cost decreased with advancing age in healthy children during balance. CP and healthy children were similarly affected by dual-task constraints during standing and walking. Children with diplegia were more affected by the DT during the postural task than children with hemiplegia. We found that adults could benefit from dual-tasking for standing. The integrated model of task prioritization might explain our results regarding postural reserve of each population.

*Keywords:* dual-tasking; posture; gait; Stroop; children; cerebral palsy

*Word count:* 6129 words

*What this paper adds:*

- Dual Task Cost decreases with advancing age in healthy children during balance and adults could benefit from dual-tasking for standing
- CP and healthy children were similarly affected by dual-task constraints during standing and walking
- Children with diplegia were more affected by the DT during the postural task than children with hemiplegia

## Introduction

Many motor tasks such as standing and walking are often performed simultaneously with a cognitive task (e.g. talking, looking for a building). Even though the control of posture and gait is traditionally considered as automatic, several studies using dual-task paradigms demonstrated a clear link between the regulation of sway or locomotion and higher-order processes <sup>1-5</sup>. In healthy adults, an improvement of standing has been reported with simple cognitive tasks <sup>6-8</sup>. These cognitive tasks withdraw participants' attention from monitoring their postural performance. This in turn, allows the motor system to function in an unconstrained mode <sup>9</sup> and promotes automatic processes for regulating posture <sup>10</sup> and gait <sup>11</sup>. However, some studies showed no effect <sup>12,13</sup> or a deterioration of standing <sup>14,15</sup> whereas most studies reported a deterioration of gait in dual-tasking <sup>4,16</sup>.

Three models are currently used to explain these apparently contradictory results: The cross-domain competition model, the U-shaped non-linear interaction model and the task prioritization model <sup>17</sup>. In the cross-domain competition model, the limited attentional and processing capacity leads to a division of and thus a competition for the attentional resources between the cognitive and postural tasks. This model can only explain why increasing the difficulty of the cognitive (or postural) task systematically involves a degradation of postural (or cognitive) performance. The performance decrement of one or both tasks is known as cognitive-motor interference (CMI; <sup>18</sup>) or dual-task cost (DTC; <sup>19</sup>). The U-shaped non-linear interaction model suggests that the performance of an easy cognitive task and /or a task with an external focus of attention can shift the focus of attention away from postural control and leads to a better postural control relative to a single-task baseline. However, increasing the difficulty of the cognitive task can result in a degradation of postural sway because of the competition of attentional resources already described in the cross-domain competition model <sup>6</sup>. Finally, the task

prioritization model postulates that subjects prioritize postural control or locomotion over cognitive activity under specific conditions (e.g., postural threat conditions). This “posture first principle” has been particularly observed in the elderly<sup>20</sup> or in patients exhibiting vestibular disorders<sup>21</sup>. Yogev-Seligmann et al.<sup>22</sup> introduced the “integrated model of task prioritization” and explained that different self-selected strategies can be handled in dual-tasking: “posture/gait-first” or “posture/gait-second” strategies depend on postural reserve and hazard estimation. People with high postural reserve and hazard estimation are able to prioritize the cognitive task during an easy motor task. If this latter becomes more complex, they allocate more resources to the posture/gait task and avoid putting their balance at risk.

Postural stability, walking performances and attentional resources increase with age. A turning-point has been observed around 7-8 years of age for standing<sup>23,24</sup>. More precisely, an improvement of gait parameters during childhood, with an increase of velocity (60–110 cm/s) and stride length (40–90 cm) has been observed between 1 and 7 years<sup>25</sup>. Characteristics of walking become steady and similar to the adults’ pattern around 7–8 years of age<sup>26</sup>. However, temporal and spatial parameters can still improve around 11-15 years, which can be explained by the continuing development of the nervous system and the changes of the anthropometric characteristics<sup>27</sup>. During childhood, some inconsistent results in dual-task conditions have also been obtained in postural control<sup>28</sup> and walking performances<sup>29-31</sup>. Olivier et al.<sup>8</sup> showed an improvement of standing in children aged 4-11 years while watching a movie. Schaefer et al.<sup>31</sup> reported an increase of gait regularity in children aged 7 and 9 years. Hagman-von Arx<sup>32</sup> reported that 6-13 years children were more affected by a motor dual-task condition (i.e., fasten and unfasten a shirt button while walking) than by a cognitive dual-task situation (i.e., listening and memorizing digits while walking). Boonyong et al.<sup>33</sup> observed a decrease of gait speed and step length when avoiding an obstacle during an auditory Stroop-task. They suggested a

developmental trend in attentional resources used to control gait in typical children. Most of these results illustrated the cross-domain competition model.

Research on children with cerebral palsy (CP) shows a poor balance control and muscular weakness<sup>34</sup>. CP can be distinguished as (1) tetraplegia affecting all four limbs; (2) diplegia, with lower limbs more compromised than upper ones; (3) hemiplegia, affecting only one side of the body; and (4) monoplegia, altering a single limb<sup>35</sup>. These children often experience ankle, knee and hip stiffness that result in an atypical posture such as the crouched posture during stance. Children with unilateral spastic CP (spastic hemiplegia) tend to have an asymmetric alignment with their weight displaced toward the non-affected side in order to compensate for weakness in the hemiparetic leg. Hemiplegic gait consists of equinus and intoeing with crouch (i.e. increased knee flexion on the hemiplegic side) in stance and a stiff knee in swing in approximately half of the subjects in the study of Wren et al.<sup>36</sup>. Diplegic gait can be characterized as stiff-kneed, crouched, and intoed, with excessive hip flexion and equinus<sup>36</sup>. Crouch is generally more prominent in children with diplegia. Previous findings reported deleterious effects of time on the walking ability of children with CP with for example an increasing likelihood of joint deformities such as a rotational misalignment between the femur and tibia<sup>37,38</sup>. Gait impairments include slower speed, reduced step length, wider step width<sup>39</sup>. Additional impairments include deficits in sensory and cognitive functions such as visuospatial attention<sup>40</sup>. CP children exhibit greater dual-task interference during standing and walking while performing a secondary cognitive task<sup>41-44</sup>. Donker et al.<sup>45</sup> described an increased Center of Pressure regularity in CP children that might be interpreted as the dynamical signature of a poor postural control.

Within this complex context, two complementary studies were conducted to investigate the typical and atypical development of standing and walking under dual-task conditions. In study 1, we explored the effects of an adapted Stroop task for children (see Methods for details)

on posture and gait by comparing younger healthy children aged 7-9 years and older healthy children aged 10-12 years with adults. In study 2, we applied the same protocol to CP and age-matched healthy children. We hypothesized that postural performances should improve in adults in the dual-task condition because of the low difficulty level of the cognitive task. However, it should impair 1) postural sway in healthy and CP children and 2) gait in all populations<sup>3</sup>. Due to impairments in both the postural control and executive attention network systems, we also predicted that CP children and especially children with diplegia would be more affected by dual-task constraints than healthy children. The expected results should confirm the “integrated model of task prioritization” and have potential clinical applications for CP children rehabilitation.

## **Method**

### *Participants*

53 children, divided in two age groups: 7–9 years (10 girls and 15 boys; mean age = 7.9 years $\pm$ 0.8), 10–12 years (11 girls and 17 boys; mean age = 10.9 years $\pm$ 0.8) and 22 adults aged 18–32 years (13 females and 9 males; mean age = 22.1 years $\pm$ 5.5) took part in the first study. Children were recruited from a sport and recreational centre and adults were recruited from the local university and from surrounding local communities.

20 children with cerebral palsy (CP) and 20 healthy age-matched children that were selected from study 1 participated in the second study. They were divided in two age groups: 7-9 years (2 females and 8 males for CP children; mean age = 8.5 years $\pm$ 0.7; 2 females and 8 males for healthy children; mean age = 8.2 years $\pm$ 0.9) and 10-12 years (5 females and 5 males for CP children; mean age = 10.4 years $\pm$ 0.8; 5 females and 5 males for healthy children; mean age = 10.3 years $\pm$ 0.8). Children with CP were referred for participation from the Grenoble University Hospital. 11 CP children were diplegic and 9 were hemiplegic. All of them were at the first level of the Gross Motor

Classification System. No exclusion criteria were specified regarding treatments, but none of the children had surgery or botulinum toxin injections within three months before the assessment.

All participants had normal or corrected to normal vision, no auditory deficits, and had no history of psychiatric disorders. No neurological disorders were reported for adults and healthy children. They were naïve to the purpose of the study and gave written informed consent as required by the Declaration of Helsinki (1964). The study was approved by the ethics research committee (n°2012-A00710-43) and parents' agreement was also obtained for the children.

### *Apparatus, procedure and data analysis*

#### Postural task

Participants stood barefoot on a force platform (OR6-AMTI1®) with feet abducted at 30°, with the heels 7 cm apart and arms positioned along the body in order to maintain a comfortable and relaxed posture. The feet position was marked on the platform to ensure the reproducibility of the position. Three 30s-trials per condition were performed and all conditions were randomized. Participants were asked to stand as still as possible.

Antero-posterior (AP) and medio-lateral (ML) displacements of the Centre of foot Pressure (CoP) were recorded. Data were collected at a frequency of 100 Hz and filtered with a second-order Butterworth filter with a cut-off frequency of 10 Hz. Five dependent variables of CoP displacements were calculated: The mean amplitude on the AP and ML axes (in mm), the mean speed on the AP and ML axes (in mm/s) and the global sample entropy to evaluate the regularity of postural sway. Sample entropy was determined using the method developed by Richman and Moorman<sup>46</sup>. As previously suggested, parameters values were  $m=3$  (number of data points to compare) and  $r=0.4$ .



## Walking task

Children and adults were instructed to walk without shoes over a 5.20 m long electronic walkway (Gaitrite®) at a self-paced speed. They started and finished walking 2.50 m before and after the walkway. A screen (200 cm x 150 cm) was placed 3 m after the walkway. Three trials per condition were performed and all conditions were randomized. In this task, data from four adults had to be discarded because of technical data collection problems: A total of 18 adults were thus included.

Relevant temporal and spatial gait parameters were calculated by the Gaitrite software<sup>3</sup>. Six parameters were analysed: Four temporal parameters - mean speed, cadence, step duration, and percentage of double limb support duration with respect to gait cycle duration - and two spatial parameters - normalized step length and normalized base of support, with respect to participants' limb length.

## Cognitive task

A dual-task paradigm, in which participants performed a Stroop task (DUAL task condition: DT) simultaneously with the postural or the walking task was used to manipulate the attentional demand of these motor tasks. It was a computerized version of an animal-Stroop test in which participants were instructed to name the body of the animal that appeared on the screen: Cow, duck, rabbit, sheep and pig. Stroop-like interference was elicited when the animal's head did not correspond to its body. Participants were required to name the animal as quickly and as accurately as possible with reference to the body and inhibit a preferred response based on identification of the animal's head<sup>47</sup>. The animals were always presented one by one on the screen and the following animal was immediately presented once participants had responded. Warm-up trials were used to introduce the task.

In a control condition (SINGLE task condition: ST), participants fixated a cross located at the centre of a white 200 cm x 150 cm screen that was placed 3 m after the walkway. Participants were asked to focus on the screen without moving and could rest whenever necessary between postural and walking trials. The single and dual tasks were presented randomly among participants in order to rule out presumable sequence effects.

Postural and walking dual-task costs (DTC) were estimated using the following equation<sup>19</sup>:  $DTC \text{ (in \%)} = \frac{ST-DT}{ST} \times (\pm) 100$  where “ST” represents participant’s motor performance in the ST condition and “DT” represents participant’s motor performance in DT condition. Positive values indicated performance improvements, whereas negatives values indicated performance impairments from single task to dual task. We used the (+) multiplier for variables showing an improvement with lower values in the dual- than single-task condition (i.e. CoP mean amplitude and speed, step duration, normalized base of support and percentage of double limb support) and the (–) multiplier for variables showing an improvement with higher values in the dual- than single-task condition (i.e. sample entropy, mean speed, cadence, normalized step length). The DTC was calculated for each variable. The mean standing/ walking DTC represented the average of the standing/walking data and was a general indicator to compare the postural and walking attentional cost with a similar cognitive task.

### *Statistical analyses*

In study 1, each dependent variable was submitted to a 3 age groups (7-9, 10-12, and adult groups) x 2 attentional conditions (ST and DT conditions) analysis of variance (ANOVA) with repeated measures on the last factor. We compared the mean DTC during the postural and the

walking tasks with a 3 age groups (7-9, 10-12, and adult groups) x 2 tasks (postural and walking) ANOVA with repeated measures on the last factor.

In study 2, each dependent variable was submitted to a 2 populations (CP and healthy) x 2 age groups (7-9, 10-12 years) x 2 attentional conditions (ST and DT conditions) ANOVA with repeated measures on the last factor. We compared the mean DTC during the postural and the walking tasks with a 2 populations (CP and healthy) x 2 age groups (7-9, 10-12 years) x 2 tasks (postural and walking) ANOVA with repeated measures on the last factor. A complementary analysis was performed between children with diplegia and hemiplegia in study 2 to see whether differences could be observed in these populations. No age effect was found across all measures. We merged therefore the 7-9 years and 10-12 years groups in order to increase the power of the analysis. We ran statistical analysis on 11 CP children with diplegia (5 girls and 6 boys; mean age = 9.3 years $\pm$ 1.3) and 9 children with hemiplegia (2 girls and 7 boys; mean age = 9.7 years $\pm$ 1.2) regardless of the age but with a comparable group mean age. Each dependent variable was submitted to a 2 deficits (diplegia and hemiplegia) x 2 attentional conditions (ST and DT conditions) analysis of variance (ANOVA) with repeated measures on the last factor.

Post hoc analyses (Newman-Keuls) were used whenever necessary to determine specific differences between populations, deficits (study 2), age groups and attentional conditions. As interactions were the main expected results, they were presented first, followed by the main effects of population and deficit (study 2), age and attentional condition. The Shapiro-Wilk tests previously confirmed the normality of data. Eta squared values  $\eta_p^2$  were also calculated for each significant effect. The  $\alpha$  level of significance was set at 0.05.

## Results

### *Study 1- Dual-task effects in healthy children*

*Postural control.* As illustrated in Figure 1, a degradation of postural control in 7-9 years children and an improvement of postural stability in adults during the DT condition were observed. Statistical analysis revealed a two-way interaction of age group x attentional task for AP and ML mean amplitude ( $F_{2, 72}=3.70$ ;  $p=0.030$ ;  $\eta_p^2 = 0.09$  and  $F_{2, 72}=4.37$ ;  $p=0.016$ ;  $\eta_p^2 =0.11$ , respectively), AP and ML mean speed ( $F_{2, 72}=4.29$ ;  $p=0.017$ ;  $\eta_p^2 = 0.11$  and  $F_{2, 72}=3.31$ ;  $p=0.042$ ;  $\eta_p^2 =0.08$ , respectively) and sample entropy ( $F_{2, 72}=6.66$ ;  $p=0.002$ ;  $\eta_p^2 =0.16$ ). Post-hoc analyses showed an increase of AP mean amplitude (almost significant  $p=0.051$ ), AP and ML mean speed ( $p<0.001$  and  $p=0.003$ , respectively) in 7-9 years children during the DT condition. Unlike the younger children, adults exhibited a decrease of AP and ML mean amplitude (almost significant  $p=0.054$  and  $p=0.005$ , respectively) and an increase of sample entropy ( $p<0.001$ ) during the DT condition. AP and ML mean amplitude was smaller in adults and in 10-12 years children than in 7-9 years children during the ST ( $p<0.01$ ) and DT conditions ( $p<0.001$ ). AP and ML speed was also smaller in adults than in 7-9 years children during the ST ( $p<0.01$ ) and DT conditions ( $p<0.001$ ). ML amplitude was smaller in adults than in 10-12 years children in the DT condition ( $p<0.001$ ). This difference was also significant for the AP and ML mean speed during the DT ( $p<0.05$ ) and ST conditions ( $p<0.01$ ).

There was a main effect of age group for AP and ML mean amplitude ( $F_{2, 72}=18.58$ ;  $p<0.001$ ;  $\eta_p^2 =0.34$  and  $F_{2, 72}=20.58$ ;  $p<0.001$ ;  $\eta_p^2 =0.36$ ), and AP and ML mean speed ( $F_{2, 72}=24.75$ ;  $p<0.001$ ;  $\eta_p^2 =0.41$  and  $F_{2, 72}=31.65$ ;  $p<0.001$ ;  $\eta_p^2 =0.47$ ). A main effect of attentional condition was found for AP mean speed ( $F_{1, 72}=17.68$ ;  $p<0.001$ ;  $\eta_p^2 =0.20$ ).

Adults showed a greater sample entropy in the DT than ST condition ( $p<0.001$ ). Sample entropy was greater in adults than in 7-9 years ( $p<0.001$ ) and 10-12 years ( $p<0.01$ ) children in the DT condition, only. Main effects of age group and attentional condition were found for this

variable ( $F_{2, 72}=4.02$ ;  $p=0.022$ ;  $\eta_p^2=0.10$  and  $F_{1, 72}=14.98$ ;  $p<0.001$ ;  $\eta_p^2=0.17$ ). No other interactions or main effects were significant.

*Walking performances.* As illustrated in Figure 2, an overall degradation of walking performances during the DT condition was observed. 7-9 years children seemed more affected by the dual-task than older children and adults. Statistical analysis revealed a two-way interaction of age group x attentional task for normalized step length ( $F_{2, 68}=5.04$ ;  $p=0.009$ ;  $\eta_p^2=0.13$ ) and normalized base of support ( $F_{2, 68}=3.57$ ;  $p=0.033$ ;  $\eta_p^2=0.09$ ). Post hoc analyses revealed that normalized step length was lower in the DT than ST condition for the 7-9 years, 10-12 years children and adults ( $p<0.001$ ). The values were almost significantly different in the ST condition between the 7-9 years children and the adults ( $p=0.058$ ). Normalized base of support was higher in the DT than ST condition at 7-9 years ( $p<0.001$ ) and was higher during the DT condition in 7-9 years children than in 10-12 years children ( $p=0.022$ ) and adults ( $p=0.010$ ).

We found a main effect of age group for mean speed ( $F_{2, 68}=7.36$ ;  $p=0.001$ ;  $\eta_p^2=0.18$ ), cadence ( $F_{2, 68}=8.55$ ;  $p<0.001$ ;  $\eta_p^2=0.20$ ), normalized base of support ( $F_{2, 68}=3.93$ ;  $p=0.024$ ;  $\eta_p^2=0.10$ ) and percentage of double limb support ( $F_{2, 68}=4.78$ ;  $p=0.011$ ;  $\eta_p^2=0.12$ ). Post hoc analyses showed that mean speed was significantly higher in adults than in 7-9 years ( $p<0.001$ ) and 10-12 years children ( $p=0.019$ ). Cadence was lower in adults than in 7-9 years ( $p<0.001$ ) and 10-12 years children ( $p=0.012$ ). Percentage of double limb support was higher in adults than in 7-9 years ( $p=0.006$ ) and 10-12 years children ( $p=0.016$ ).

A main effect of attentional task was observed for mean speed ( $F_{1, 68}=102.99$ ;  $p<0.001$ ;  $\eta_p^2=0.60$ ), cadence ( $F_{1, 68}=20.37$ ;  $p<0.001$ ;  $\eta_p^2=0.23$ ), step duration ( $F_{1, 68}=13.49$ ;  $p<0.001$ ;  $\eta_p^2=0.17$ ), normalized step length ( $F_{1, 68}=159.79$ ;  $p<0.001$ ;  $\eta_p^2=0.70$ ), normalized base of support ( $F_{1, 68}=19.76$ ;  $p<0.001$ ;  $\eta_p^2=0.23$ ) and percentage of double limb support ( $F_{1, 68}=6.20$ ;  $p=0.015$ ;

$\eta_p^2=0.08$ ). Mean speed, cadence, and normalized step length decreased whereas step duration, normalized base of support and percentage of double limb support increased in the DT condition. No other interactions or main effects were significant.

*Cognitive performances.* We observed lower cognitive performances in 7-9 and 10-12 years children as compared to adults. A main effect of age group was found for the percentage and number of correct responses during the postural task ( $F_{2, 72}=3.45$ ;  $p=0.037$ ;  $\eta_p^2=0.09$ ;  $F_{2, 72}=87.32$ ;  $p<0.001$ ;  $\eta_p^2=0.7$ , respectively) and for the percentage of correct responses during the walking task ( $F_{1, 68}=4.50$ ;  $p=0.015$ ;  $\eta_p^2=0.11$ ). Post hoc tests indicated lower percentages of correct responses in 7-9 years and 10-12 years children than in adults in the postural ( $p=0.048$  and  $p=0.025$ , respectively) and the walking tasks ( $p=0.013$  and  $p=0.011$ , respectively). The number of correct responses was lower in 7-9 years than in 10-12 years children and adults ( $p<0.001$ ) and was lower in 10-12 years children than in adults ( $p<0.001$ ).

*Dual task cost.* Our protocol also enabled the comparison between standing and walking with the same cognitive task and showed that the overall DTC was higher during the walking than the postural task in all groups. Statistical analysis indicated a main effect of task with higher negative values during walking ( $F_{1, 68}=10.40$ ;  $p=0.002$ ;  $\eta_p^2=0.13$ ; -10.72% vs. -16.5% at 7-9 years; -2.45% vs. -10.97% at 10-12 years; 18.71% vs. -6.28% in adults; see Table 2 for more details on all postural and walking parameters). We found also a main effect of age ( $F_{2, 68}=6.02$ ;  $p=0.004$ ;  $\eta_p^2=0.15$ ) with higher DTC in 7-9 years and 10-12 years children than in adults ( $p=0.004$  for both comparisons).

*Study 2- Dual-task effects in children with cerebral palsy*

*Postural control.* As summarized in Figures 3 and 4, healthy and CP children showed a degradation of standing during the DT condition whatever the age. A two-way interaction of population x attentional condition was found for the ML mean amplitude ( $F_{1,36}=5.83$ ;  $p=0.021$ ;  $\eta_p^2=0.14$ ). Post hoc analyses revealed an increase of ML mean amplitude in the CP group during the DT condition ( $p=0.002$ ) and a greater ML amplitude in the CP than healthy children in the DT ( $p=0.002$ ) and ST ( $p=0.042$ ) conditions.

A main effect of population was observed for the AP and ML mean amplitude ( $F_{1,36}=5.69$ ;  $p=0.022$ ;  $\eta_p^2=0.14$  and  $F_{1,36}=10.24$ ;  $p=0.003$ ;  $\eta_p^2=0.22$ , respectively), AP and ML mean speed ( $F_{1,36}=10.40$ ;  $p=0.003$ ;  $\eta_p^2=0.22$  and  $F_{1,36}=26.12$ ;  $p<0.001$ ;  $\eta_p^2=0.42$ , respectively) and sample entropy ( $F_{1,36}=6.88$ ;  $p=0.013$ ;  $\eta_p^2=0.16$ ). CoP displacements were larger and sample entropy was lower in CP than healthy children. A main effect of attentional condition was observed for the AP and ML mean amplitude ( $F_{1,36}=6.06$ ;  $p=0.019$ ;  $\eta_p^2=0.14$  and  $F_{1,36}=5.64$ ,  $p=0.023$ ;  $\eta_p^2=0.14$ ), and AP and ML mean speed ( $F_{1,36}=17.07$ ;  $p<0.001$ ;  $\eta_p^2=0.32$  and  $F_{1,36}=14.72$ ;  $p<0.001$ ;  $\eta_p^2=0.29$ , respectively). CoP displacements were greater in the DT condition. No other interactions or main effects were significant.

*Walking performances.* As summarized in Figures 5 and 6, a degradation of walking performances was observed, which was quite similar across populations and age groups during the DT condition. The two-way interaction of age group x attentional condition was significant for normalized step length, only ( $F_{1,38}=6.16$ ;  $p=0.018$ ;  $\eta_p^2=0.15$ ): Values were lower in the DT than ST condition for CP and healthy children ( $p<0.001$ ).

A main effect of attentional task was found for mean speed ( $F_{1,38}=54.10$ ;  $p<0.001$ ;  $\eta_p^2=0.60$ ), cadence ( $F_{1,38}=19.26$ ;  $p<0.001$ ;  $\eta_p^2=0.35$ ), step duration ( $F_{1,38}=25.53$ ;  $p<0.001$ ;  $\eta_p^2=0.41$ ), normalized step length ( $F_{1,38}=84.97$ ;  $p<0.001$ ;  $\eta_p^2=0.70$ ), normalized base of support ( $F_{1,38}=84.97$ ;  $p<0.001$ ;  $\eta_p^2=0.70$ ), normalized base of support ( $F_{1,38}=84.97$ ;  $p<0.001$ ;  $\eta_p^2=0.70$ ), normalized base of support ( $F_{1,38}=84.97$ ;  $p<0.001$ ;  $\eta_p^2=0.70$ ).

$_{38}=5.15; p=0.029; \eta_p^2=0.13$ ) and percentage of double limb support ( $F_{1, 38}=10.37; p=0.003; \eta_p^2=0.22$ ). Mean speed, cadence, and normalized step length decreased whereas step duration, normalized base of support and percentage of double limb support increased in the DT condition for both populations and both age groups. No other interactions or main effects were significant.

*Cognitive performances.* We observed lower cognitive performances in 7-9 than in 10-12 years children and in CP children during the postural task, only. Main effects of age group and population were found for the number of correct responses ( $F_{1, 36}=13.029; p<0.001; \eta_p^2=0.27$ ;  $F_{1, 36}=13.879; p<0.001; \eta_p^2=0.28$ ). The number of correct responses was lower in the younger children and in CP children. No other interactions or main effects were significant.

*Dual task cost.* The main effect of task was almost significant ( $p=0.059$ ). The overall DTC was higher during the walking than the standing task in all groups except in the 7-9 years healthy children, with higher negative values during walking (-20.49% vs. -27.89% in 7-9 years CP children; -25.93% vs. -17.46% in 7-9 years healthy children; -6.60% vs. -11.94% in 10-12 years CP children; -1.14% vs. -19.44% in 10-12 years healthy children; see Table 3 for more details on all postural and walking parameters).

*Effect of hemiplegia or diplegia.* Statistical analysis revealed a two-way interaction of deficit x attentional condition for ML mean amplitude ( $F_{1, 18}=12.649; p=0.002; \eta_p^2=0.41$ ) and sample entropy ( $F_{1, 18}=10.349; p=0.005; \eta_p^2=0.37$ ). The interaction was almost significant for AP amplitude ( $p=0.089$ ). Post hoc analysis indicated that ML amplitude was significantly higher in DT than in ST condition for the children with diplegia, only ( $p<0.001$ ). Sample entropy was higher in children with hemiplegia in DT than ST condition ( $p=0.005$ ) and higher in children with



hemiplegia than children with diplegia in the DT condition ( $p=0.04$ ). For the walking task, a main effect of attentional condition was reported for mean speed ( $F_{1,18}=26.219$ ;  $p<0.001$ ;  $\eta p^2 = 0.59$ ), cadence ( $F_{1,18}=11.61$ ;  $p=0.003$ ;  $\eta p^2 = 0.39$ ), step duration ( $F_{1,18}=9.59$ ;  $p=0.006$ ;  $\eta p^2 = 0.35$ ), percentage of double support ( $F_{1,18}=6.254$ ;  $p=0.022$ ;  $\eta p^2 = 0.26$ ) and step length ( $F_{1,18}=35.66$ ;  $p<0.001$ ;  $\eta p^2 = 0.66$ ), with lower values in DT than ST for mean speed, cadence and step length. The step duration and the percentage of double limb support were higher in DT. However, we found no main effect of the deficit for all gait and cognitive parameters. The cognitive performances were similar in children with diplegia and hemiplegia. There was only a main effect of age for the number of correct responses, with lower values in younger children ( $F_{1,17}=5.379$ ;  $p=0.033$ ;  $\eta p^2 = 0.24$ ). There was also no difference for the DTC in the postural and locomotor tasks between children with hemiplegia and diplegia.

## Discussion

In these two studies, we compared the standing and walking performances of healthy and CP children, and adults in dual-task conditions. DTC decreased with advancing age in healthy children during balance and was higher during walking in all populations. We found that adults could benefit from dual-tasking for standing. Unexpectedly, the main findings indicated that CP and healthy children were similarly affected by dual-task constraints during standing and walking. However, children with diplegia were more affected by the DT during the postural task than children with hemiplegia.

### *Dual-task effects in healthy children and adults*

Our results confirmed that postural control becomes more efficient throughout early childhood and early adulthood. We showed that DTC decreases with advancing age and observed

a decrease of postural performances in younger children (i.e., higher CoP displacements) and an improvement in adults (i.e., smaller CoP displacements and higher sample entropy) under dual-task constraints. CoP displacements and sample entropy were similar under single- and dual-tasks in older children. There were cognitive benefits for adults but cognitive costs for younger children. This suggested that standing in children aged 7-12 years is still maturing and not as automated as in adults. An overall degradation of gait performances appeared in all age groups. Previous studies reported a similar decrease in velocity that was associated with a decrease in cadence and an increase in percentage of double limb support duration during dual-task conditions for adults and children<sup>3</sup>. The fact that the DT interfered with gait control in children and adults is also in accordance with the literature<sup>18,3</sup> and confirmed that walking automaticity is never complete, also in adulthood.

The model best explaining these different results is probably the “integrated model of task prioritization”<sup>22</sup>. According to this model, young adults have generally intact postural reserves and high hazard estimation that enable to focus on the cognitive task. The Stroop-animal task, which was primarily selected for children, can be considered as a low demanding task for adults in the standing condition because we observed a facilitation of the automatic control processes. This easy cognitive task led to an external focus of attention and therefore to an improvement of motor performances in adults, only. Children have less postural reserve than adults and the cognitive task might have been too demanding especially for younger children and for the walking task in all groups. Lajoie et al.<sup>1</sup> showed that walking needed more resources than standing, probably because gait requires a continuous regulation and integration of sensory inputs. Our protocol confirmed that the overall DTC was higher during the walking than the postural task in all groups (see Table 2).

*Dual task effects in children with cerebral palsy*

Balance performances were generally weaker in CP than healthy children under single- and dual-tasks as illustrated by higher CoP displacements and a more regular sway. However cognitive cost of standing was quite similar between the two populations. CP children responded similarly to healthy age-matched children to the dual-task constraints despite their pathological state. Moreover, children with diplegia showed lower postural performances in DT condition than children with hemiplegia. These latter had a higher sample entropy, reflecting an overall better postural control. These results confirmed those of Donker et al.<sup>45</sup> and Schmit<sup>44</sup> and were in line with the “pathological regularity versus healthy complexity” idea of Goldberger et al.<sup>48</sup>. It postulates that less “complex” or more “regular” physiological time series reflect less effective physiological control. This increased CoP regularity observed in CP children could be interpreted as the dynamical signature of an altered postural control<sup>45</sup> and is more prominent in children with diplegia: the DTC was higher in this population and these children exhibited a more regular sway.

Interestingly and unlike previous findings, we found that CP children exhibited the same walking performances than healthy children whatever the single- and dual-task conditions<sup>49-51</sup>. There was no effect of the CP deficit on gait parameters. CP children generally exhibit reduced gait velocity, step length and increased step time and variability. A simple explanation might be that the present CP children aged 7–12 years with GMFCS 1 experienced standing and walking for years as healthy children: The attention needed for standing and walking was relatively the same than for healthy children and the degree of posture/gait automaticity was quite similar. Contrary to the study of Katz-Leurer et al.<sup>51</sup>, our CP participants were under Botulinum Toxin treatment since 3 to 6 months and were therefore in rather good shape to perform the various tasks. Recent findings showed that an external attentional focus promoted better balance

performance for healthy and CP participants and further attenuated differences between these children<sup>43</sup>. However, we did not confirm these results with the Stroop-animal task. Both single- and dual-tasking showed postural deficiencies in CP children and highlighted aspects of motor control that remain intact in these children. The overall DTC was higher during the walking than the standing task in all groups except in the 7-9 years healthy children (see Table 3). No DTC difference was observed between children with hemiplegia and diplegia, indicating that the cost of postural and locomotor control was quite similar for them.

#### *Specific effects of the Stroop-animal task*

The decline of standing and walking performances observed in all groups (except in adults during standing) indicates that motor and cognitive tasks interfere with each other. Automaticity depends heavily on motor task difficulty<sup>29</sup>. Our findings suggested that the development of executive processes involved in the Stroop interference may proceed during healthy and pathological childhood<sup>52</sup> and/ or that healthy and CP children may require some practice of dual-tasking to develop an efficient division of attentional resources and thus postural/walking improvement.

Previous findings showed that visual tasks require the greatest attentional demand in children and young adults<sup>3,4</sup> and that there is an overlap of neural networks for balance control and visual-spatial tasks<sup>53</sup>. These neural structures are still in development in children. The Stroop-animal task is a discrimination and decision-making task<sup>4</sup> requiring considerable visual processing, especially in younger children, and might therefore explain the decline of their postural and locomotor performances. Although Ruffieux et al.<sup>28</sup> reported inconsistent results about the effects of age on dual-tasking ability, our results showed an age-related difference between healthy children and adults and a similar behavior between CP and healthy children.

However, it is hard to clearly determine at which age children's performance reaches the level of young adults, probably after 12 years of age. Palluel et al.<sup>54</sup> suggested that the information processing capacity is still limited in adolescents aged 14-15 years. In addition, it is reasonable to assume that the age for reaching an adults' level of performance is also dependent on 1.) the type and difficulty of the task and 2.) individuals' level of ability. Ruffieux et al.<sup>28</sup> suggested that tasks should be adjusted to each participant in order to obtain a comparable cognitive load in all of them.

### *The integrated model of task prioritization*

The simultaneous performance of two attention-demanding tasks not only causes a competition for attention resources, but it also challenges the brain to decide how to prioritize the two tasks. In general, prioritization may be determined by the motivation to minimize danger and maximize pleasure<sup>22</sup>. It is also important to differentiate between focus of attention and performance. Some subjects might change the focus of attention without performance decreases until the focus has considerably shifted. Although young CP and healthy participants have lower postural reserve than adults, they might have exhibited an unconscious strategy to prioritize the cognitive task altering the overall motor performance because their posture and gait were not challenged enough. This "posture/gait-second" strategy has already been observed during low demanding standing or walking conditions<sup>22</sup>. Inhibiting a preferred response based on identification of the animal's head during the Stroop-animal task may have been perceived more challenging than maintaining small CoP displacements or preferred gait parameters. The hazard estimation process takes into account personal limitations and may impact the prioritization to a greater extent in the school-aged children<sup>55</sup>. Our results might confirm that healthy and CP children are able to exhibit healthy risk judgments<sup>29</sup>. In adults, the improvement of postural

control could be attributed to a stiffening strategy<sup>56</sup> but we found less regular CoP fluctuations during dual-tasking, suggesting higher degrees of freedom, a reduced attentional involvement in the postural regulation and thus greater automaticity while standing<sup>57,58</sup>. The stiffening strategy has already been described in children by Blanchard et al.<sup>59</sup> but was not observed in the current results. However, these authors only used conventional sway parameters for their interpretation of the results (i.e., length of center of pressure path, sway range, and variability of sway).

## **Conclusion**

To summarize, the main issue addressed in this experiment was to further identify the attentional demand of standing and walking during typical and atypical ontogenesis. In dual-task conditions, DTC decreased with age and was higher during walking in healthy children and adults. CP and healthy children were similarly affected by dual-task constraints during standing and walking. However, children with diplegia were more affected by the DT during the postural task than children with hemiplegia. Adults could benefit from the DT during balance, only. The integrated model of task prioritization might explain our results regarding postural reserve of each population.

As already mentioned by Schmit et al.<sup>44</sup>, our study suggested that the single performance of quiet stance or gait may not accurately reveal functional characteristics of standing and walking in children with CP. The apparent deficits of these children might reflect different strategies or adaptations because simultaneous execution of motor and cognitive tasks is embedded in the daily life of every child. Examining postural control and gait in the context of dual-tasking exposes aspects of motor control that may remain intact in CP children (e.g., the ability to adapt standing/gait to perform a visual task) and other aspects that may be disrupted (e.g., the ability to allocate attention in such a way as to enhance performance). It is also worth to

502 mention that children within the same mobility classification level show an evident and consistent  
503 pattern of differences. For example, children with hemiplegia clearly show better gait and lower  
504 extremity mobility scores when compared to those with diplegia <sup>60</sup>. Considering standing and gait  
505 within a framework of functional behavior seems to be crucial in this population.

## References

- 1 Lajoie Y, Teasdale N, Bard C, Fleury M. Attention demands for static and dynamic equilibrium. *Experimental Brain Research* 1993; **97**: 139-44.
- 2 Pellecchia GL. Postural sway increases with attentional demands of concurrent cognitive task. *Gait and Posture* 2003; **18**: 29-34.
- 3 Chauvel G, Palluel E, Brandao A, Barbieri G, Nougier V, Olivier I. Attentional load of walking in children aged 7-12 and in adults. *Gait Posture* 2017; **56**: 95-9.
- 4 Al-Yahya E, Dawes H, Smith L, Dennis A, Howells K, Cockburn J. Cognitive motor interference while walking: a systematic review and meta-analysis. *Neurosci Biobehav Rev* 2011; **35**: 715-28.
- 5 Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture* 2002; **16**: 1-14.
- 6 Huxhold O, Li SC, Schmiedek F, Lindenberger U. Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention. *Brain Res Bull* 2006; **69**: 294-305.
- 7 Polskaia N, Lajoie Y. Reducing postural sway by concurrently performing challenging cognitive tasks. *Hum Mov Sci* 2016; **46**: 177-83.
- 8 Olivier I, Palluel E, Nougier V. Effects of attentional focus on postural sway in children and adults. *Exp Brain Res* 2008; **185**: 341-5.
- 9 Richer N, Saunders D, Polskaia N, Lajoie Y. The effects of attentional focus and cognitive tasks on postural sway may be the result of automaticity. *Gait Posture* 2017; **54**: 45-9.
- 10 Wulf G, McNevin NH, Shea CH. The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology. A: Human Experimental Psychology* 2001; **54**: 1143-54.
- 11 Verrel J, Lovden M, Schellenbach M, Schaefer S, Lindenberger U. Interacting effects of cognitive load and adult age on the regularity of whole-body motion during treadmill walking. *Psychology and aging* 2009; **24**: 75-81.
- 12 Kerr B, Condon S, McDonald L. Cognitive spatial processing and the regulation of posture. *Journal of Experimental Psychology. Human Perception and Performance* 1985; **11**: 617-22.
- 13 Remaud A, Boyas S, Caron GA, Bilodeau M. Attentional demands associated with postural control depend on task difficulty and visual condition. *J Mot Behav* 2012; **44**: 329-40.
- 14 Dault MC, Geurts AC, Mulder TW, Duysens J. Postural control and cognitive task performance in healthy participants while balancing on different support-surface configurations. *Gait Posture* 2001; **14**: 248-55.
- 15 Woollacott M, Vander Velde T. Non-visual spatial tasks reveal increased interactions with stance postural control. *Brain Res* 2008; **1208**: 95-102.
- 16 Lin MI, Lin KH. Walking while Performing Working Memory Tasks Changes the Prefrontal Cortex Hemodynamic Activations and Gait Kinematics. *Frontiers in behavioral neuroscience* 2016; **10**: 92.
- 17 Lacour M, Bernard-Demanze L, Dumitrescu M. Posture control, aging, and attention resources: models and posture-analysis methods. *Neurophysiol Clin* 2008; **38**: 411-21.
- 18 Patel P, Lamar M, Bhatt T. Effect of type of cognitive task and walking speed on cognitive-motor interference during dual-task walking. *Neuroscience* 2014; **260**: 140-8.
- 19 Luder B, Kiss R, Granacher U. Single- and Dual-Task Balance Training Are Equally Effective in Youth. *Frontiers in psychology* 2018; **9**: 912.



- 20 Shumway-Cook A, Woollacott M, Kerns KA, Baldwin M. The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *J Gerontol A Biol Sci Med Sci* 1997; **52**: M232-40.
- 21 Andersson G, Hagman J, Talianzadeh R, Svedberg A, Larsen HC. Dual-task study of cognitive and postural interference in patients with vestibular disorders. *Otol Neurotol* 2003; **24**: 289-93.
- 22 Yogeve-Seligmann G, Hausdorff JM, Giladi N. Do we always prioritize balance when walking? Towards an integrated model of task prioritization. *Movement disorders : official journal of the Movement Disorder Society* 2012; **27**: 765-70.
- 23 Olivier I, Cuisinier R, Vaugoyeau M, Nougier V, Assaiante C. Dual-task study of cognitive and postural interference in 7-year-olds and adults. *Neuroreport* 2007; **18**: 817-21.
- 24 Rival C, Ceyte H, Olivier I. Developmental changes of static standing balance in children. *Neuroscience Letters* 2005; **376**: 133-6.
- 25 Sutherland DH, Olshen R, Cooper L, Woo SL. The development of mature gait. *J Bone Joint Surg Am* 1980; **62**: 336-53.
- 26 Kraan CM, Tan AHJ, Cornish KM. The developmental dynamics of gait maturation with a focus on spatiotemporal measures. *Gait Posture* 2017; **51**: 208-17.
- 27 Hausdorff JM, Zemani L, Peng C, Goldberger AL. Maturation of gait dynamics: stride-to-stride variability and its temporal organization in children. *J Appl Physiol (1985)* 1999; **86**: 1040-7.
- 28 Ruffieux J, Keller M, Lauber B, Taube W. Changes in Standing and Walking Performance Under Dual-Task Conditions Across the Lifespan. *Sports Med* 2015; **45**: 1739-58.
- 29 Schott N, Klotzbier TJ. Profiles of Cognitive-Motor Interference During Walking in Children: Does the Motor or the Cognitive Task Matter? *Frontiers in psychology* 2018; **9**: 947.
- 30 Saxena S, Cinar E, Majnemer A, Gagnon I. Does dual tasking ability change with age across childhood and adolescence? A systematic scoping review. *International journal of developmental neuroscience : the official journal of the International Society for Developmental Neuroscience* 2017; **58**: 35-49.
- 31 Schaefer S, Jagenow D, Verrel J, Lindenberger U. The influence of cognitive load and walking speed on gait regularity in children and young adults. *Gait Posture* 2015; **41**: 258-62.
- 32 Hagmann-von Arx P, Manicolo O, Lemola S, Grob A. Walking in School-Aged Children in a Dual-Task Paradigm Is Related to Age But Not to Cognition, Motor Behavior, Injuries, or Psychosocial Functioning. *Frontiers in psychology* 2016; **7**: 352.
- 33 Boonyong S, Siu KC, van Donkelaar P, Chou LS, Woollacott MH. Development of postural control during gait in typically developing children: the effects of dual-task conditions. *Gait Posture* 2012; **35**: 428-34.
- 34 Woollacott M, Shumway-Cook A. Postural dysfunction during standing and walking in children with cerebral palsy: what are the underlying problems and what new therapies might improve balance? *Neural plasticity* 2005; **12**: 211-9; discussion 63-72.
- 35 Ferrari A, Bergamini L, Guerzoni G, Calderara S, Bicocchi N, Vitetta G, Borghi C, Neviani R. Gait-Based Diplegia Classification Using LSMT Networks. *Journal of healthcare engineering* 2019; **2019**: 3796898.
- 36 Wren TA, Rethlefsen S, Kay RM. Prevalence of specific gait abnormalities in children with cerebral palsy: influence of cerebral palsy subtype, age, and previous surgery. *J Pediatr Orthop* 2005; **25**: 79-83.
- 37 Bell KJ, Ounpuu S, DeLuca PA, Romness MJ. Natural progression of gait in children with cerebral palsy. *J Pediatr Orthop* 2002; **22**: 677-82.

- 38 Johnson DC, Damiano DL, Abel MF. The evolution of gait in childhood and adolescent cerebral palsy. *J Pediatr Orthop* 1997; **17**: 392-6.
- 39 Galli M, Cimolin V, Rigoldi C, Tenore N, Albertini G. Gait patterns in hemiplegic children with Cerebral Palsy: comparison of right and left hemiplegia. *Research in developmental disabilities* 2010; **31**: 1340-5.
- 40 Ickx G, Hatem SM, Riquelme I, Friel KM, Henne C, Araneda R, Gordon AM, Bleyenheuft Y. Impairments of Visuospatial Attention in Children with Unilateral Spastic Cerebral Palsy. *Neural plasticity* 2018; **2018**: 1435808.
- 41 Reilly DS, Woollacott MH, van Donkelaar P, Saavedra S. The interaction between executive attention and postural control in dual-task conditions: children with cerebral palsy. *Arch Phys Med Rehabil* 2008; **89**: 834-42.
- 42 Hung YC, Meredith GS. Influence of dual task constraints on gait performance and bimanual coordination during walking in children with unilateral cerebral palsy. *Research in developmental disabilities* 2014; **35**: 755-60.
- 43 Schmit J, Riley M, Cummins-Sebree S, Schmitt L, Shockley K. Functional Task Constraints Foster Enhanced Postural Control in Children With Cerebral Palsy. *Physical therapy* 2016; **96**: 348-54.
- 44 Schmit J, Riley M, Cummins-Sebree S, Schmitt L, Shockley K. Children with cerebral palsy effectively modulate postural control to perform a supra-postural task. *Gait Posture* 2015; **42**: 49-53.
- 45 Donker SF, Ledebt A, Roerdink M, Savelsbergh GJ, Beek PJ. Children with cerebral palsy exhibit greater and more regular postural sway than typically developing children. *Exp Brain Res* 2008; **184**: 363-70.
- 46 Richman JS, Moorman JR. Physiological time-series analysis using approximate entropy and sample entropy. *American journal of physiology. Heart and circulatory physiology* 2000; **278**: H2039-49.
- 47 Wright I, Waterman M, Prescott H, Murdoch-Eaton D. A new Stroop-like measure of inhibitory function development: typical developmental trends. *Journal of child psychology and psychiatry, and allied disciplines* 2003; **44**: 561-75.
- 48 Goldberger AL, Amaral LA, Hausdorff JM, Ivanov P, Peng CK, Stanley HE. Fractal dynamics in physiology: alterations with disease and aging. *Proc Natl Acad Sci U S A* 2002; **99 Suppl 1**: 2466-72.
- 49 Hsue BJ, Miller F, Su FC. The dynamic balance of the children with cerebral palsy and typical developing during gait. Part I: Spatial relationship between COM and COP trajectories. *Gait Posture* 2009; **29**: 465-70.
- 50 Hsue BJ, Miller F, Su FC. The dynamic balance of the children with cerebral palsy and typical developing during gait Part II: Instantaneous velocity and acceleration of COM and COP and their relationship. *Gait Posture* 2009; **29**: 471-6.
- 51 Katz-Leurer M, Rotem H, Meyer S. Effect of concurrent cognitive tasks on temporo-spatial parameters of gait among children with cerebral palsy and typically developed controls. *Developmental neurorehabilitation* 2014; **17**: 363-7.
- 52 Adleman NE, Menon V, Blasey CM, White CD, Warsofsky IS, Glover GH, Reiss AL. A developmental fMRI study of the Stroop color-word task. *NeuroImage* 2002; **16**: 61-75.
- 53 Barra J, Bray A, Sahni V, Golding JF, Gresty MA. Increasing cognitive load with increasing balance challenge: recipe for catastrophe. *Exp Brain Res* 2006; **174**: 734-45.
- 54 Palluel E, Nougier V, Olivier I. Postural control and attentional demand during adolescence. *Brain Res* 2010; **1358**: 151-9.

- 55 Abbruzzese LD, Rao AK, Bellows R, Figueroa K, Levy J, Lim E, Puccio L. Effects of manual task complexity on gait parameters in school-aged children and adults. *Gait Posture* 2014; **40**: 658-63.
- 56 McNevin NH, Wulf G. Attentional focus on supra-postural tasks affects postural control. *Hum Mov Sci* 2002; **21**: 187-202.
- 57 Stins JF, Roerdink M, Beek PJ. To freeze or not to freeze? Affective and cognitive perturbations have markedly different effects on postural control. *Human Movement Science* 2011; **30**: 190-202.
- 58 Donker SF, Roerdink M, Greven AJ, Beek PJ. Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. *Exp Brain Res* 2007; **181**: 1-11.
- 59 Blanchard Y, Carey S, Coffey J, Cohen A, Harris T, Michlik S, Pellecchia GL. The influence of concurrent cognitive tasks on postural sway in children. *Pediatr Phys Ther* 2005; **17**: 189-93.
- 60 Damiano D, Abel M, Romness M, Oeffinger D, Tylkowski C, Gorton G, Bagley A, Nicholson D, Barnes D, Calmes J, Kryscio R, Rogers S. Comparing functional profiles of children with hemiplegic and diplegic cerebral palsy in GMFCS Levels I and II: Are separate classifications needed? *Dev Med Child Neurol* 2006; **48**: 797-803.

## FIGURE CAPTION

Figure 1: Mean performance and standard deviation for the five postural parameters (AP/ML mean amplitude and speed, sample entropy (SampEn)) and for the two conditions (ST, DT) as a function of age group (7-9 years, 10-12 years, and adults). SampEn combines AP and ML axes. For readability purposes, significant differences between age groups were not drawn on the figure (please refer to text for details). \*  $p < 0.05$  and \*\* $p < 0.01$

Figure 2: Mean performance and standard deviation for the six gait parameters (mean speed, cadence, step duration, normalized step length, normalized base of support and percentage of double limb support) and for the two conditions (ST, DT) as a function of age group (7-9 years, 10-12 years, and adults). \*  $p < 0.05$  and \*\* $p < 0.01$

Figures 3 and 4: Mean performance and standard deviation for the five postural parameters (AP/ML mean amplitude and speed, sample entropy (SampEn)) and for the two conditions (ST, DT) as a function of population (CP, healthy children) and age group (7-9 years, 10-12 years). SampEn combines AP and ML axes. \*  $p < 0.05$  and \*\* $p < 0.01$

Figures 5 and 6: Mean performance and standard deviation for the six gait parameters (mean speed, cadence, step duration, normalized step length, normalized base of support and percentage of double limb support) and for the two conditions (ST, DT) as a function of population (CP, healthy children) and age group (7-9 years, 10-12 years). \*  $p < 0.05$  and \*\* $p < 0.01$

# TABLES

Table 1. Characteristics of the sample for study 2

	CP (n)	TD (n)
Total	20	20
Sex		
Female	7	7
Male	13	13
Distribution of cerebral palsy		
Diplegia	11	N/A
Hemiplegia	9	
Gross Motor Functional Classification		
I	20	N/A
Orthotic use		
Yes	0	N/A
No	20	

CP, cerebral palsy; TD, typically developing.

Table 2. DTC for standing and walking tasks in healthy children and adults (study 1). Values represent means and standard deviation (SD).

	7-9 years		10-12 years		Adults	
	Mean	SD	Mean	SD	Mean	SD
<b>Standing performances (DTC in %)</b>						
AP mean amplitude	-18,41	59,02	-3,39	32,80	13,08	29,88
ML mean amplitude	-7,81	41,06	-9,61	45,63	20,49	33,42
AP mean speed	-28,54	54,39	-16,39	13,58	-8,76	18,91
ML mean speed	-20,44	62,46	-6,81	18,78	1,79	21,23
Sample Entropy	21,60	67,33	23,93	49,90	66,97	76,12
Mean DTC	-10,72	56,85	-2,45	32,14	18,71	35,91
<b>Walking performances (DTC in %)</b>						
Mean speed	-19,01	15,04	-15,44	9,51	-10,43	8,10
Cadence	-7,06	12,23	-4,71	6,49	-3,53	5,90
Step duration	-15,36	30,01	-5,24	7,33	-4,14	6,83
Normalized step length	-13,35	7,13	-11,61	7,91	-7,33	4,17
Normalized base of support	-34,11	48,84	-19,10	41,91	-5,42	16,89
Double limb support	-10,11	19,42	-9,71	10,47	-6,84	10,82
Mean DTC	-16,50	22,11	-10,97	13,94	-6,28	8,79

Table 3. DTC for standing and walking tasks in CP and healthy children (study 2). Values represent means and standard deviation (SD).

	Children with CP				Healthy children			
	7-9 years		10-12 years		7-9 years		10-12 years	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<b>Standing performances (DTC in %)</b>								
AP mean amplitude	-19,35	28,90	-14,75	32,83	-41,90	87,41	-8,03	36,97
ML mean amplitude	-24,05	30,18	-32,72	49,56	-14,19	62,37	7,80	17,11
AP mean speed	-20,29	14,54	-10,94	14,90	-44,57	83,39	-19,70	9,76
ML mean speed	-25,79	16,46	-16,35	19,59	-38,53	97,92	-1,92	22,33
Sample Entropy	-12,96	34,19	41,76	89,44	9,53	64,65	16,15	52,38
Mean DTC	-20,49	24,85	-6,60	41,26	-25,93	79,15	-1,14	27,71
<b>Walking performances (DTC in %)</b>								
Mean speed	-22,43	14,56	-16,12	18,37	-25,32	18,67	-24,93	16,19
Cadence	-10,04	11,14	-7,54	12,54	-11,98	14,88	-9,52	14,30
Step duration	-12,60	15,67	-11,12	17,15	-10,85	9,19	-6,53	4,58
Normalized step length	-10,70	7,19	-10,87	8,96	-16,73	8,61	-18,05	10,61
Normalized base of support	-89,59	61,56	-4,50	34,37	-29,23	37,21	-49,11	67,88
Double limb support	-22,00	20,57	-21,49	57,17	-10,63	7,85	-8,53	14,15
Mean DTC	-27,89	21,78	-11,94	24,76	-17,46	16,07	-19,44	21,28

