

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

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1	Running Head: Dual tasking in CP and	d healthy children
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4		healthy children
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## Abstract

26	Simultaneous execution of motor and cognitive tasks is embedded in the daily life of						
27	children. 53 children of 7–12 years and 22 adults (study 1), 20 healthy children and 20 children of						
28	7-12 years with cerebral palsy (study 2) performed a Stroop-animal task simultaneously with a						
29	standing or a walking task in order to determine the attentional demand of postural control and						
30	locomotion. Dual-task cost decreased with advancing age in healthy children during balance. CP						
31	and healthy children were similarly affected by dual-task constraints during standing and						
32	walking. Children with diplegia were more affected by the DT during the postural task than						
33	children with hemiplegia. We found that adults could benefit from dual-tasking for standing. The						
34	integrated model of task prioritization might explain our results regarding postural reserve of						
35	each population.						
36							
37	Keywords: dual-tasking; posture; gait; Stroop; children; cerebral palsy						
38							
39	Word count: 6129 words						
40							
41	What this paper adds:						
42	• Dual Task Cost decreases with advancing age in healthy children during balance and						
43	adults could benefit from dual-tasking for standing						
44	• CP and healthy children were similarly affected by dual-task constraints during standing						
45	and walking						
46	• Children with diplegia were more affected by the DT during the postural task than						
47	children with hemiplegia						
48							

#### 49 Introduction

50 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 51 is traditionally considered as automatic, several studies using dual-task paradigms demonstrated a 52 53 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 54 55 cognitive tasks withdraw participants' attention from monitoring their postural performance. This 56 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 57 deterioration of standing <sup>14,15</sup> whereas most studies reported a deterioration of gait in dual-tasking 58 4,16 59

60 Three models are currently used to explain these apparently contradictory results: The 61 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 62 63 processing capacity leads to a division of and thus a competition for the attentional resources 64 between the cognitive and postural tasks. This model can only explain why increasing the 65 difficulty of the cognitive (or postural) task systematically involves a degradation of postural (or 66 cognitive) performance. The performance decrement of one or both tasks is known as cognitivemotor interference (CMI; <sup>18</sup>) or dual-task cost (DTC; <sup>19</sup>). The U-shaped non-linear interaction 67 model suggests that the performance of an easy cognitive task and /or a task with an external 68 69 focus of attention can shift the focus of attention away from postural control and leads to a better 70 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 71 72 attentional resources already described in the cross-domain competition model <sup>6</sup>. Finally, the task

73	prioritization model postulates that subjects prioritize postural control or locomotion over
74	cognitive activity under specific conditions (e.g., postural threat conditions). This "posture first
75	principle" has been particularly observed in the elderly <sup>20</sup> or in patients exhibiting vestibular
76	disorders <sup>21</sup> . Yogev-Seligmann et al. <sup>22</sup> introduced the "integrated model of task prioritization"
77	and explained that different self-selected strategies can be handled in dual-tasking: "posture/gait-
78	first" or "posture/gait-second" strategies depend on postural reserve and hazard estimation.
79	People with high postural reserve and hazard estimation are able to prioritize the cognitive task
80	during an easy motor task. If this latter becomes more complex, they allocate more resources to
81	the posture/gait task and avoid putting their balance at risk.
82	Postural stability, walking performances and attentional resources increase with age. A
83	turning-point has been observed around 7-8 years of age for standing <sup>23,24</sup> . More precisely, an
84	improvement of gait parameters during childhood, with an increase of velocity (60-110 cm/s)
85	and stride length (40–90 cm) has been observed between 1 and 7 years <sup>25</sup> . Characteristics of
86	walking become steady and similar to the adults' pattern around 7–8 years of age <sup>26</sup> . However,
87	temporal and spatial parameters can still improve around 11-15 years, which can be explained by
88	the continuing development of the nervous system and the changes of the anthropometric
89	characteristics <sup>27</sup> . During childhood, some inconsistent results in dual-task conditions have also
90	been obtained in postural control <sup>28</sup> and walking performances <sup>29-31</sup> . Olivier et al. <sup>8</sup> showed an
91	improvement of standing in children aged 4-11 years while watching a movie. Schaefer el al. <sup>31</sup>
92	reported an increase of gait regularity in children aged 7 and 9 years. Hagman-von Arx $^{32}$
93	reported that 6-13 years children were more affected by a motor dual-task condition (i.e., fasten
94	and unfasten a shirt button while walking) than by a cognitive dual-task situation (i.e., listening
95	and memorizing digits while walking). Boonyong et al. <sup>33</sup> observed a decrease of gait speed and
96	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 theseresults illustrated the cross-domain competition model.

99 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 100 101 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 102 103 and hip stiffness that result in an atypical posture such as the crouched posture during stance. 104 Children with unilateral spastic CP (spastic hemiplegia) tend to have an asymmetric alignment 105 with their weight displaced toward the non-affected side in order to compensate for weakness in 106 the hemiparetic leg. Hemiplegic gait consists of equinus and intoeing with crouch (i.e. increased 107 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, 108 crouched, and intoed, with excessive hip flexion and equinus<sup>36</sup>. Crouch is generally more 109 110 prominent in children with diplegia. Previous findings reported deleterious effects of time on the 111 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 112 slower speed, reduced step length, wider step width <sup>39</sup>. Additional impairments include deficits 113 114 in sensory and cognitive functions such as visuospatial attention <sup>40</sup>. CP children exhibit greater 115 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 116 117 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) 121 on posture and gait by comparing younger healthy children aged 7-9 years and older healthy 122 children aged 10-12 years with adults. In study 2, we applied the same protocol to CP and age-123 matched healthy children. We hypothesized that postural performances should improve in adults 124 in the dual-task condition because of the low difficulty level of the cognitive task. However, it 125 should impair 1) postural sway in healthy and CP children and 2) gait in all populations<sup>3</sup>. Due to 126 impairments in both the postural control and executive attention network systems, we also 127 predicted that CP children and especially children with diplegia would be more affected by dual-128 task constraints than healthy children. The expected results should confirm the "integrated model 129 of task prioritization "and have potential clinical applications for CP children rehabilitation. 130

131 Method

#### 132 Participants

133 53 children, divided in two age groups: 7–9 years (10 girls and 15 boys; mean age = 7.9 134 years $\pm 0.8$ ), 10–12 years (11 girls and 17 boys; mean age = 10.9 years $\pm 0.8$ ) and 22 adults aged 135 18–32 years (13 females and 9 males; mean age = 22.1 years $\pm 5.5$ ) took part in the first study. 136 Children were recruited from a sport and recreational centre and adults were recruited from the 137 local university and from surrounding local communities.

138 20 children with cerebral palsy (CP) and 20 healthy age-matched children that were selected 139 from study 1 participated in the second study. They were divided in two age groups: 7-9 years (2 140 females and 8 males for CP children; mean age = 8.5 years $\pm 0.7$ ; 2 females and 8 males for healthy 141 children; mean age = 8.2 years $\pm 0.9$ ) and 10-12 years (5 females and 5 males for CP children; mean 142 age = 10.4 years $\pm 0.8$ ; 5 females and 5 males for healthy children; mean age = 10.3 years $\pm 0.8$ ). 143 Children with CP were referred for participation from the Grenoble University Hospital. 11 CP 144 children were diplegic and 9 were hemiplegic. All of them were at the first level of the Gross Motor

145 Classification System. No exclusion criteria were specified regarding treatments, but none of the146 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.

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#### 153 Apparatus, procedure and data analysis

#### 154 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.

160 Antero-posterior (AP) and medio-lateral (ML) displacements of the Centre of foot 161 Pressure (CoP) were recorded. Data were collected at a frequency of 100 Hz and filtered with a 162 second-order Butterworth filter with a cut-off frequency of 10 Hz. Five dependent variables of 163 CoP displacements were calculated: The mean amplitude on the AP and ML axes (in mm), the 164 mean speed on the AP and ML axes (in mm/s) and the global sample entropy to evaluate the 165 regularity of postural sway. Sample entropy was determined using the method developed by Richman and Moorman  $^{46}$ . As previously suggested, parameters values were m= 3 (number of 166 167 data points to compare) and r = 0.4.

Walking task

170 Children and adults were instructed to walk without shoes over a 5.20 m long electronic 171 walkway (Gaitrite®) at a self-paced speed. They started and finished walking 2.50 m before and 172 after the walkway. A screen (200 cm x 150 cm) was placed 3 m after the walkway. Three trials 173 per condition were performed and all conditions were randomized. In this task, data from four 174 adults had to be discarded because of technical data collection problems: A total of 18 adults 175 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.

181

182 Cognitive task

183 A dual-task paradigm, in which participants performed a Stroop task (DUAL task 184 condition: DT) simultaneously with the postural or the walking task was used to manipulate the 185 attentional demand of these motor tasks. It was a computerized version of an animal-Stroop test 186 in which participants were instructed to name the body of the animal that appeared on the screen: 187 Cow, duck, rabbit, sheep and pig. Stroop-like interference was elicited when the animal's head 188 did not correspond to its body. Participants were required to name the animal as quickly and as 189 accurately as possible with reference to the body and inhibit a preferred response based on 190 identification of the animal's head <sup>47</sup>. The animals were always presented one by one on the 191 screen and the following animal was immediately presented once participants had responded. 192 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.

198 Postural and walking dual-task costs (DTC) were estimated using the following equation <sup>19</sup>: DTC (in %) =  $\frac{ST - DT}{ST} \times (\pm)$  100 where "ST" represents participant's motor performance in the 199 ST condition and "DT" represents participant's motor performance in DT condition. Positive 200 201 values indicated performance improvements, whereas negatives values indicated performance 202 impairments from single task to dual task. We used the (+) multiplier for variables showing an 203 improvement with lower values in the dual- than single-task condition (i.e. CoP mean amplitude 204 and speed, step duration, normalized base of support and percentage of double limb support) and 205 the (-) multiplier for variables showing an improvement with higher values in the dual- than 206 single-task condition (i.e. sample entropy, mean speed, cadence, normalized step length). The 207 DTC was calculated for each variable. The mean standing/ walking DTC represented the average 208 of the standing/walking data and was a general indicator to compare the postural and walking 209 attentional cost with a similar cognitive task.

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#### 211 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.

217 In study 2, each dependent variable was submitted to a 2 populations (CP and healthy) x 2 218 age groups (7-9, 10-12 years) x 2 attentional conditions (ST and DT conditions) ANOVA with 219 repeated measures on the last factor. We compared the mean DTC during the postural and the 220 walking tasks with a 2 populations (CP and healthy) x 2 age groups (7-9, 10-12 years) x 2 tasks 221 (postural and walking) ANOVA with repeated measures on the last factor. A complementary 222 analysis was performed between children with diplegia and hemiplegia in study 2 to see whether 223 differences could be observed in these populations. No age effect was found across all measures. 224 We merged therefore the 7-9 years and 10-12 years groups in order to increase the power of the 225 analysis. We ran statistical analysis on 11 CP children with diplegia (5 girls and 6 boys; mean age 226 = 9.3 years $\pm 1.3$ ) and 9 children with hemiplegia (2 girls and 7 boys; mean age = 9.7 years $\pm 1.2$ ) 227 regardless of the age but with a comparable group mean age. Each dependent variable was 228 submitted to a 2 deficits (diplegia and hemiplegia) x 2 attentional conditions (ST and DT 229 conditions) analysis of variance (ANOVA) with repeated measures on the last factor. 230 Post hoc analyses (Newman-Keuls) were used whenever necessary to determine specific 231 differences between populations, deficits (study 2), age groups and attentional conditions. As 232 interactions were the main expected results, they were presented first, followed by the main 233 effects of population and deficit (study 2), age and attentional condition. The Shapiro-Wilk tests 234 previously confirmed the normality of data. Eta squared values  $\eta_p^2$  were also calculated for each

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- 237 **Results**
- 238 Study 1- Dual-task effects in healthy children

significant effect. The  $\alpha$  level of significance was set at 0.05.

239	Postural control. As illustrated in Figure 1, a degradation of postural control in 7-9 years
240	children and an improvement of postural stability in adults during the DT condition were
241	observed. Statistical analysis revealed a two-way interaction of age group x attentional task for
242	AP and ML mean amplitude (F <sub>2, 72</sub> =3.70; $p$ =0.030; $\eta_p^2 = 0.09$ and F <sub>2, 72</sub> =4.37; $p$ =0.016; $\eta_p^2 = 0.11$ ,
243	respectively), AP and ML mean speed (F <sub>2, 72</sub> =4.29; $p=0.017$ ; $\eta_p^2 = 0.11$ and F <sub>2, 72</sub> =3.31; $p=0.042$ ;
244	$\eta_p^2 = 0.08$ , respectively) and sample entropy (F <sub>2, 72</sub> =6.66; $p=0.002$ ; $\eta_p^2 = 0.16$ ). Post-hoc analyses
245	showed an increase of AP mean amplitude (almost significant $p=0.051$ ), AP and ML mean speed
246	( $p$ <0.001 and $p$ =0.003, respectively) in 7-9 years children during the DT condition. Unlike the
247	younger children, adults exhibited a decrease of AP and ML mean amplitude (almost significant
248	p=0.054 and $p=0.005$ , respectively) and an increase of sample entropy ( $p<0.001$ ) during the DT
249	condition. AP and ML mean amplitude was smaller in adults and in 10-12 years children than in
250	7-9 years children during the ST ( $p \le 0.01$ ) and DT conditions ( $p \le 0.001$ ). AP and ML speed was
251	also smaller in adults than in 7-9 years children during the ST ( $p$ <0.01) and DT conditions
252	( $p$ <0.001). ML amplitude was smaller in adults than in 10-12 years children in the DT condition
253	( $p$ <0.001). This difference was also significant for the AP and ML mean speed during the DT
254	( <i>p</i> <0.05) and ST conditions ( <i>p</i> <0.01).

255 There was a main effect of age group for AP and ML mean amplitude (F<sub>2, 72</sub>=18.58;

256  $p < 0.001; \eta_p^2 = 0.34$  and F<sub>2, 72</sub>=20.58;  $p < 0.001; \eta_p^2 = 0.36$ ), and AP and ML mean speed (F<sub>2</sub>,

257 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

258 condition was found for AP mean speed (F<sub>1, 72</sub>=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 262 variable (F<sub>2, 72</sub>=4.02; p=0.022;  $\eta_p^2=0.10$  and F<sub>1, 72</sub>=14.98; p<0.001;  $\eta_p^2=0.17$ ). No other 263 interactions or main effects were significant.

264

265 Walking performances. As illustrated in Figure 2, an overall degradation of walking 266 performances during the DT condition was observed. 7-9 years children seemed more affected by 267 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<sub>2, 68</sub>=5.04; p=0.009;  $\eta_p^2$ =0.13) and 268 269 normalized base of support (F<sub>2,68</sub>=3.57; p=0.033;  $\eta_p^2=0.09$ ). Post hoc analyses revealed that 270 normalized step length was lower in the DT than ST condition for the 7-9 years, 10-12 years 271 children and adults (p < 0.001). The values were almost significantly different in the ST condition 272 between the 7-9 years children and the adults (p=0.058). Normalized base of support was higher 273 in the DT than ST condition at 7-9 years (p < 0.001) and was higher during the DT condition in 7-274 9 years children than in 10-12 years children (p=0.022) and adults (p=0.010). 275 We found a main effect of age group for mean speed (F<sub>2,68</sub>=7.36; p=0.001;  $\eta_p^2=0.18$ ), 276 cadence (F<sub>2, 68</sub>=8.55; p < 0.001;  $\eta_p^2 = 0.20$ ), normalized base of support (F<sub>2, 68</sub>=3.93; p = 0.024; 277  $\eta_p^2=0.10$ ) and percentage of double limb support (F<sub>2,68</sub>=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) 278 279 and 10-12 years children (p=0.019). Cadence was lower in adults than in 7-9 years (p<0.001) and 280 10-12 years children (p=0.012). Percentage of double limb support was higher in adults than in 7-281 9 years (p=0.006) and 10-12 years children (p=0.016). 282 A main effect of attentional task was observed for mean speed ( $F_{1,68}=102.99$ ; p<0.001; 283  $\eta_p^2 = 0.60$ , cadence (F<sub>1,68</sub>=20.37; p<0.001;  $\eta_p^2 = 0.23$ ), step duration (F<sub>1,68</sub>=13.49; p<0.001;  $\eta_p^2 = 0.17$ ), normalized step length (F<sub>1, 68</sub>=159.79; p<0.001;  $\eta_p^2 = 0.70$ ), normalized base of support 284 285  $(F_{1,68}=19.76, p < 0.001; \eta_p^2 = 0.23)$  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.

288 No other interactions or main effects were significant.

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290 Cognitive performances. We observed lower cognitive performances in 7-9 and 10-12 291 years children as compared to adults. A main effect of age group was found for the percentage 292 and number of correct responses during the postural task (F<sub>2, 72</sub>=3.45; p=0.037;  $\eta_p^2=0.09$ ; F<sub>2</sub>, 293  $\gamma_2 = 87.32$ ; p < 0.001;  $\eta_p^2 = 0.7$ , respectively) and for the percentage of correct responses during the 294 walking task (F<sub>1,68</sub>=4.50; p=0.015;  $\eta_p^2=0.11$ ). Post hoc tests indicated lower percentages of 295 correct responses in 7-9 years and 10-12 years children than in adults in the postural (p=0.048296 and p=0.025, respectively) and the walking tasks (p=0.013 and p=0.011, respectively). The 297 number of correct responses was lower in 7-9 years than in 10-12 years children and adults 298 (p < 0.001) and was lower in 10-12 years children than in adults (p < 0.001).

299

300 Dual task cost. Our protocol also enabled the comparison between standing and walking 301 with the same cognitive task and showed that the overall DTC was higher during the walking 302 than the postural task in all groups. Statistical analysis indicated a main effect of task with higher 303 negative values during walking (F<sub>1,68</sub>=10.40; p=0.002;  $\eta_p^2=0.13$ ; -10.72% vs. -16.5% at 7-9 304 years; -2.45% vs. -10.97% at 10-12 years; 18.71% vs. -6.28% in adults; see Table 2 for more 305 details on all postural and walking parameters). We found also a main effect of age (F<sub>2, 68</sub>=6.02; 306 p=0.004;  $\eta_p^2=0.15$ ) with higher DTC in 7-9 years and 10-12 years children than in adults 307 (p=0.004 for both comparisons).

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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<sub>1, 36</sub>=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.

316 A main effect of population was observed for the AP and ML mean amplitude ( $F_{1,}$ 

317 36=5.69; p=0.022;  $\eta_p^2$ =0.14 and F<sub>1,36</sub>=10.24; p=0.003;  $\eta_p^2$ =0.22, respectively), AP and ML mean

318 speed (F<sub>1,36</sub>=10.40; p=0.003;  $\eta_p^2$ =0.22 and F<sub>1,36</sub>=26.12; p<0.001;  $\eta_p^2$ =0.42, respectively) and

sample entropy (F<sub>1,36</sub>=6.88; p=0.013;  $\eta_p^2$ =0.16). CoP displacements were larger and sample

320 entropy was lower in CP than healthy children. A main effect of attentional condition was

321 observed for the AP and ML mean amplitude (F<sub>1, 36</sub>=6.06; p=0.019;  $\eta_p^2$ =0.14 and F<sub>1, 36</sub>=5.64,

322 p=0.023;  $\eta_p^2$ =0.14), and AP and ML mean speed (F<sub>1,36</sub>=17.07; p<0.001;  $\eta_p^2$ =0.32 and

323 F<sub>1,36</sub>=14.72; p<0.001;  $\eta_p^2$ =0.29, respectively). CoP displacements were greater in the DT

324 condition. No other interactions or main effects were significant.

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*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<sub>1, 38</sub>=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).

331 A main effect of attentional task was found for mean speed (F<sub>1, 38</sub>=54.10; p < 0.001;  $\eta_p^2$ 

332 =0.60), cadence (F<sub>1,38</sub>=19.26; p < 0.001;  $\eta_p^2 = 0.35$ ), step duration (F<sub>1,38</sub>=25.53; p < 0.001;  $\eta_p^2$ 

333 =0.41), normalized step length (F<sub>1, 38</sub>=84.97; p < 0.001;  $\eta_p^2 = 0.70$ ), normalized base of support (F<sub>1</sub>,

 $_{38}=5.15$ ; p=0.029;  $\eta_p^2=0.13$ ) and percentage of double limb support (F<sub>1,38</sub>=10.37; p=0.003;  $\eta_p^2$ 334 335 =0.22). Mean speed, cadence, and normalized step length decreased whereas step duration, 336 normalized base of support and percentage of double limb support increased in the DT condition 337 for both populations and both age groups. No other interactions or main effects were significant. 338 339 *Cognitive performances.* We observed lower cognitive performances in 7-9 than in 10-12 340 years children and in CP children during the postural task, only. Main effects of age group and 341 population were found for the number of correct responses (F<sub>1,36</sub>=13.029; p < 0.001;  $\eta_p^2 = 0.27$ ; F<sub>1</sub>,  $_{36}=13.879$ ; p<0.001;  $\eta_p^2=0.28$ ). The number of correct responses was lower in the younger 342 343 children and in CP children. No other interactions or main effects were significant. 344 345 Dual task cost. The main effect of task was almost significant (p=0.059). The overall DTC 346 was higher during the walking than the standing task in all groups except in the 7-9 years healthy 347 children, with higher negative values during walking (-20.49% vs. -27.89% in 7-9 years CP 348 children; -25.93% vs. -17.46% in 7-9 years healthy children; -6.60% vs. -11.94% in 10-12 years 349 CP children; -1.14% vs. -19.44% in 10-12 years healthy children; see Table 3 for more details on 350 all postural and walking parameters). 351 352 *Effect of hemiplegia or diplegia.* Statistical analysis revealed a two-way interaction of 353 deficit x attentional condition for ML mean amplitude (F<sub>1,18</sub>=12.649; p=0.002;  $\eta p^2 = 0.41$ ) and sample entropy (F<sub>1, 18</sub>=10.349; p=0.005;  $\eta p^2$ =0.37). The interaction was almost significant for 354

in DT than in ST condition for the children with diplegia, only (p < 0.001). Sample entropy was

AP amplitude (*p*=0.089). Post hoc analysis indicated that ML amplitude was significantly higher

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357 higher in children with hemiplegia in DT than ST condition (p=0.005) and higher in children with

358 hemiplegia than children with diplegia in the DT condition (p=0.04). For the walking task, a main 359 effect of attentional condition was reported for mean speed (F<sub>1.18</sub>=26.219; p < 0.001;  $\eta p^2 = 0.59$ ), 360 cadence (F<sub>1,18</sub>=11.61; p=0.003;  $\eta p^2 = 0.39$ ), step duration (F<sub>1,18</sub>=9.59; p=0.006;  $\eta p^2 = 0.35$ ), 361 percentage of double support ( $F_{1, 18}=6.254$ ; p=0.022;  $\eta p^2 = 0.26$ ) and step length ( $F_{1, 18}=35.66$ ; 362 p < 0.001;  $\eta p^2 = 0.66$ ), with lower values in DT than ST for mean speed, cadence and step length. 363 The step duration and the percentage of double limb support were higher in DT. However, we 364 found no main effect of the deficit for all gait and cognitive parameters. The cognitive 365 performances were similar in children with diplegia and hemiplegia. There was only a main 366 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 367 368 locomotor tasks between children with hemiplegia and diplegia.

369

#### **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.

378

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

380 Our results confirmed that postural control becomes more efficient throughout early

381 childhood and early adulthood. We showed that DTC decreases with advancing age and observed

382 a decrease of postural performances in younger children (i.e., higher CoP displacements) and an 383 improvement in adults (i.e., smaller CoP displacements and higher sample entropy) under dual-384 task constraints. CoP displacements and sample entropy were similar under single- and dual-tasks 385 in older children. There were cognitive benefits for adults but cognitive costs for younger 386 children. This suggested that standing in children aged 7-12 years is still maturating and not as 387 automated as in adults. An overall degradation of gait performances appeared in all age groups. 388 Previous studies reported a similar decrease in velocity that was associated with a decrease in 389 cadence and an increase in percentage of double limb support duration during dual-task 390 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 391 392 never complete, also in adulthood.

393 The model best explaining these different results is probably the "integrated model of task 394 prioritization"<sup>22</sup>. According to this model, young adults have generally intact postural reserves 395 and high hazard estimation that enable to focus on the cognitive task. The Stroop-animal task, 396 which was primarily selected for children, can be considered as a low demanding task for adults 397 in the standing condition because we observed a facilitation of the automatic control processes. 398 This easy cognitive task led to an external focus of attention and therefore to an improvement of 399 motor performances in adults, only. Children have less postural reserve than adults and the 400 cognitive task might have been too demanding especially for younger children and for the 401 walking task in all groups. Lajoie et al.<sup>1</sup> showed that walking needed more resources than 402 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 403 404 postural task in all groups (see Table 2).

#### Dual task effects in children with cerebral palsy

407 Balance performances were generally weaker in CP than healthy children under single-408 and dual-tasks as illustrated by higher CoP displacements and a more regular sway. However 409 cognitive cost of standing was quiet similar between the two populations. CP children responded 410 similarly to healthy age-matched children to the dual-task constraints despite their pathological 411 state. Moreover, children with diplegia showed lower postural performances in DT condition than 412 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 413 with the "pathological regularity versus healthy complexity" idea of Goldberger et al. <sup>48</sup>. It 414 415 postulates that less "complex" or more "regular" physiological time series reflect less effective 416 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 417 418 with diplegia: the DTC was higher in this population and these children exhibited a more regular 419 sway.

420 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>. 421 422 There was no effect of the CP deficit on gait parameters. CP children generally exhibit reduced 423 gait velocity, step length and increased step time and variability. A simple explanation might be 424 that the present CP children aged 7-12 years with GMFCS 1 experienced standing and walking 425 for years as healthy children: The attention needed for standing and walking was relatively the 426 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 427 428 treatment since 3 to 6 months and were therefore in rather good shape to perform the various 429 tasks. Recent findings showed that an external attentional focus promoted better balance

430 performance for healthy and CP participants and further attenuated differences between these 431 children <sup>43</sup>. However, we did not confirm these results with the Stroop-animal task. Both single-432 and dual-tasking showed postural deficiencies in CP children and highlighted aspects of motor 433 control that remain intact in these children. The overall DTC was higher during the walking than 434 the standing task in all groups except in the 7-9 years healthy children (see Table 3). No DTC 435 difference was observed between children with hemiplegia and diplegia, indicating that the cost 436 of postural and locomotor control was quiet similar for them.

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#### 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 dualtasking 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 446 children and young adults <sup>3,4</sup> and that there is an overlap of neural networks for balance control 447 and visual-spatial tasks <sup>53</sup>. These neural structures are still in development in children. The 448 Stroop-animal task is a discrimination and decision-making task <sup>4</sup> requiring considerable visual 449 450 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 451 452 about the effects of age on dual-tasking ability, our results showed an age-related difference 453 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.

461

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#### The integrated model of task prioritization

463 The simultaneous performance of two attention-demanding tasks not only causes a 464 competition for attention resources, but it also challenges the brain to decide how to prioritize the 465 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 466 467 performance. Some subjects might change the focus of attention without performance decreases 468 until the focus has considerably shifted. Although young CP and healthy participants have lower 469 postural reserve than adults, they might have exhibited an unconscious strategy to prioritize the 470 cognitive task altering the overall motor performance because their posture and gait were not 471 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 472 473 identification of the animal's head during the Stroop-animal task may have been perceived more 474 challenging than maintaining small CoP displacements or preferred gait parameters. The hazard 475 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 476 children are able to exhibit healthy risk judgments<sup>29</sup>. In adults, the improvement of postural 477

478 control could be attributed to a stiffening strategy <sup>56</sup> but we found less regular CoP fluctuations 479 during dual-tasking, suggesting higher degrees of freedom, a reduced attentional involvement in 480 the postural regulation and thus greater automaticity while standing <sup>57,58</sup>. The stiffening strategy 481 has already been described in children by Blanchard et al. <sup>59</sup> but was not observed in the current 482 results. However, these authors only used conventional sway parameters for their interpretation 483 of the results (i.e., length of center of pressure path, sway range, and variability of sway).

484

#### 485 **Conclusion**

486 To summarize, the main issue addressed in this experiment was to further identify 487 the attentional demand of standing and walking during typical and atypical ontogenesis. In dual-488 task conditions, DTC decreased with age and was higher during walking in healthy children and 489 adults. CP and healthy children were similarly affected by dual-task constraints during standing 490 and walking. However, children with diplegia were more affected by the DT during the postural 491 task than children with hemiplegia. Adults could benefit from the DT during balance, only. The 492 integrated model of task prioritization might explain our results regarding postural reserve of 493 each population.

As already mentioned by Schmit et al.<sup>44</sup>, our study suggested that the single performance 494 495 of quiet stance or gait may not accurately reveal functional characteristics of standing and 496 walking in children with CP. The apparent deficits of these children might reflect different 497 strategies or adaptations because simultaneous execution of motor and cognitive tasks is 498 embedded in the daily life of every child. Examining postural control and gait in the context of 499 dual-tasking exposes aspects of motor control that may remain intact in CP children (e.g., the 500 ability to adapt standing/gait to perform a visual task) and other aspects that may be disrupted 501 (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.

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### **FIGURE CAPTION**

666	Figure 1: Mean performance and standard deviation for the five postural parameters (AP/ML
667	mean amplitude and speed, sample entropy (SampEn)) and for the two conditions (ST,
668	DT) as a function of age group (7-9 years, 10-12 years, and adults). SampEn combines
669	AP and ML axes. For readability purposes, significant differences between age groups
670	were not drawn on the figure (please refer to text for details). * $p<0.05$ and ** $p<0.01$
671	
672	Figure 2: Mean performance and standard deviation for the six gait parameters (mean speed,
673	cadence, step duration, normalized step length, normalized base of support and percentage
674	of double limb support) and for the two conditions (ST, DT) as a function of age group
675	(7-9 years, 10-12 years, and adults). * p<0.05 and **p<0.01
676	
677	Figures 3 and 4: Mean performance and standard deviation for the five postural parameters
678	(AP/ML mean amplitude and speed, sample entropy (SampEn)) and for the two
679	conditions (ST, DT) as a function of population (CP, healthy children) and age group (7-9
680	years, 10-12 years). SampEn combines AP and ML axes. * p<0.05 and **p<0.01
681	
682	Figures 5 and 6: Mean performance and standard deviation for the six gait parameters (mean
683	speed, cadence, step duration, normalized step length, normalized base of support and
684	percentage of double limb support) and for the two conditions (ST, DT) as a function of
685	population (CP, healthy children) and age group (7-9 years, 10-12 years). * p<0.05 and
686	**p<0.01
687	

	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	

689 Table 1. Characteristics of the sample for study 2

690 691 692 CP, cerebral palsy; TD, typically developing.

## 693 Table 2. DTC for standing and walking tasks in healthy children and adults (study 1). Values

- 694 represent means and standard deviation (SD).
- 695

	7-9 years		10-12 years		Adults	
	Mean	SD	Mean	SD	Mean	SD
Standing performances (DTC in						
%)						
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
Walking performances (DTC in %)						
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	
Standing performances (DTC in %)									
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 <i>,</i> 38	
Mean DTC	-20,49	24,85	-6,60	41,26	-25,93	79,15	-1,14	27,71	
Walking performances (DTC in %)									
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	