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Research Report

Postural control and attentional demand during adolescence

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ABSTRACT

In the present study we aimed to determine the attentional cost of postural control during adolescence by studying the influence of a cognitive task on concurrent postural control. 38 teenagers aged 12 to 17 years and 13 young adults (mean age = 26.1) stood barefoot on a force platform in a semi-tandem position. A dual-task paradigm consisted of performing a Stroop or a *COUNTING BACKWARD* task while simultaneously standing quietly on a firm or foam support surface. Different centre of pressure (CoP) measures were calculated (90% confidence ellipse area, mean velocity, root mean square on the antero-posterior (AP) and medio-lateral (ML) axes). The number and percentage of correct responses in the cognitive tasks were also recorded. Our results indicate (1) higher values of surface, ML mean velocity and ML RMS in the *COUNTING BACKWARD* task in adolescents aged 12 to 15 than in teenagers aged 16 to 17 and in adults, regardless of the complexity of the postural task and, (2) better cognitive performances in the Stroop than in the *COUNTING BACKWARD* task. The difference in the dual-task performance between the different age groups and particularly the existence of a turning point around 14–15 years of age might be due to 1) difficulties in properly allocating attentional resources to two simultaneous tasks and/or, 2) the inability to manage increased cognitive requests because of a limited information processing capacity in adolescents aged 14–15 years.

1. Introduction

Although it has often been argued that undisturbed quiet standing is automatically regulated, several studies using dual-task paradigms demonstrated a clear link between the regulation of sway and higher-order processes (Lajoie et al., 1993). Even in young adults, a minimum amount of attention is required to stand upright. The more challenging the postural task (e.g., feet-together or unipedal stance), the greater the required attentional resources (Dault et al., 2001). Cognitive (e.g., reading, counting backward, and spelling words) and postural tasks (e.g., upright stance and one-leg balance) require common cognitive mechanisms that involve a conflicting relationship when both tasks are performed simultaneously (Kerr et al., 1985). Increasing the level of difficulty of the cognitive task involves either increased (Blanchard et al., 2005), decreased (Andersson et al., 2002) or unchanged (Kerr et al., 1985) centre of foot pressure (CoP) excursions. Conversely, the performance of the cognitive task (e.g., backward counting and reaction-time task) can be compromised by a simultaneous control of quiet stance in adults with calf vibration (Andersson et al., 2002), on a beam (Barra et al., 2006) or with suppression or perturbation of sensory information in the elderly (Teasdale et al., 1993). The

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performance can also remain unchanged (Andersson et al., 2002; Barra et al., 2006).

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 (Lacour et al., 2008). 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 task systematically involves a degradation of postural performances. The U-shaped non-linear interaction model suggests that the performance of an easy cognitive task can shift the focus of attention away from postural control and lead 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 (Huxhold et al., 2006). Finally, the task prioritization model postulates that subjects prioritize postural control over cognitive activity under specific conditions (e.g., postural threat conditions). This "posture first principle" has been particularly observed in the elderly (Shumway-Cook et al., 1997) or in patients exhibiting vestibular disorders (Andersson et al., 2003).

In daily life, postural tasks are commonly paired with cognitive tasks (e.g., talking while standing or walking). The efficiency of the cognitive mechanisms (Kirshenbaum et al., 2001; Olivier et al., 2008) and postural stability (Rival et al., 2005) improve during childhood, with a turning point occurring at 7–8 years of age for postural stability (Olivier et al., 2007; Rival et al., 2005). For example, Blanchard et al. (2005) observed a longer CoP path length when performing a concurrent cognitive task (i.e., reading aloud and counting backward) between 8 and 10 years of age as compared to adults. The children also exhibited a smaller range and less variability, indicating the use of a different strategy than adults. Schmid et al. (2007) also found that the cognitive load affected postural control in 9-year-old children. On the contrary, Reilly et al. (2008) did not find a decrease of postural sway while performing a visual working memory task in children from 7 to 12 years of age. The interference (i.e., increase of CoP displacements) was only significant for 4- to 6-year-old children. Since the maturation of the central mechanisms involved in postural control and cognitive tasks occur at the same time, they argued that the interference observed in the younger children could either be due to (1) the limited attentional resources available to perform both tasks simultaneously, (2) the greater allocation of attentional resources needed to control the most difficult postural task (e.g., the tandem Romberg position is more attentionally demanding than the wide stance position) or (3) a combination of both factors. Cognitive development is also supported by changes in patterns of brain activation, including enhancement of activation in critical areas and attenuation in others. For example, Adleman et al. (2002) showed that Stroop task-related functional development of the parietal lobe occurs between 12 and 16 years of age. An increase of activation occurs with age in a number of brain regions thought to be important in performance of the Stroop task, including the left lateral prefrontal cortex, left parietal/parieto-occipital cortex, and left anterior cingulate cortex. An increase in prefrontal activation continues into adulthood. This age-related increase in activation occurs in conjunction with better behavioral performance on some measures of the Stroop task.

Few studies have simultaneously manipulated the complexity of postural and cognitive tasks. Age-related differences in cognitive and postural dual-task performance were only evaluated by Olivier et al. (2007, 2010). They manipulated the level of difficulty of the cognitive and postural tasks simultaneously. A modified Stroop task, in which performance continues to develop over childhood (Adleman et al., 2002; Durston and Casey, 2006; Jongen and Jonkman, 2008), was combined with a semi-tandem postural task. Results showed a turning point at around 8 years of age and suggested that adult behaviour was still not reached at 11 years of age. The purpose of the present study was therefore to assess the influence of the same kind of concurrent cognitive task on postural control in adolescents. Adolescence is a dynamic period of development involving rapid changes in body size, shape and composition. It affects both development (Giedd et al., 1999) and behaviour (Buchanan et al., 1992). The onset of puberty corresponds to a biological age of approximately 11 years in girls and 13 years in boys (Tanner et al., 1975). There is a significant inter-individual variation in the timing and tempo of puberty (Rogol et al., 2002). Although this period is characterized by a rapid physical growth, the body scheme disturbance occurring during adolescence does not involve a degradation of postural control: body height, body mass and age seem to have no impact on sway parameters (Lebiedowska and Syczewska, 2000). The development of visual, vestibular and somatosensory systems may account for age-related changes in balance control to a greater extent (Nolan et al., 2005). Nolan et al. (2005) found no sex differences after 10 years of age when standing with eyes open, suggesting that boys and girls exhibit a similar postural control strategy after 10. Hirabayashi and Iwasaki (1995) proposed that teenagers of 14 years of age do not demonstrate the same visual or vestibular control as adults. Moreover, 14- to 15-year-old teenagers transiently neglect proprioceptive cues in the control of orientation and body stabilization (Viel et al., 2009). They rely more on visual information and their balance performance are weaker than those of adults. The stabilisation processes are particularly affected in males. Conflicting results reported that all balance parameters improve from 5 to 18 years of age, with small changes between 8 and 18 years of age (Wolff et al., 1998).

The attentional resources devoted to postural control in adolescents remain unknown. A dual-task paradigm consisting of a Stroop or a counting backward task and a quiet stance task was used to determine the attentional demand of postural control in teenagers aged 12 to 17. We hypothesized an age-related difference in the influence of a concurrent cognitive task on postural control.

2. Results

No gender or support surface effect was observed on cognitive and postural performances (Table 1).

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2.1. *Cognitive performance (see Fig. 1 and Table 2)*

The number of correct responses was analysed in order to compare the information processing speed across age Table 2. It revealed a main effect of age ($F_{3,42}=5.05$, $p<0.01$), a main effect of cognitive task ($F_{2,84}=705.70$, $p<0.001$) and crucially, an interaction of age × cognitive task ($F_{6,84}=7.14$, $p<0.001$). As illustrated in Fig. 1, post hoc analysis indicated a decreased number of correct responses between the cognitive tasks, with higher values observed in the *COLOUR NEUTRAL* than in the *COLOUR INCONGRUENT* and *COUNTING BACKWARD* conditions for group 1 (age range 12–13 years) ($p_s<0.001$), group 2 (age range 14–15 years) ($p_s<0.001$), group 3 (age range 14–15 years) ($p_s<0.001$) and adults ($p_s<0.001$).

Analysis of the percentage of correct responses showed a main effect of age $F_{3,42}=4.99$, $p<0.01$), a main effect of cognitive task ($F_{2,84}=71.64$, $p<0.001$) and an interaction of age × cognitive task ($F_{6,84}=3.09$, $p<0.01$). As illustrated in Fig. 1, post hoc analysis indicated that the percentage of correct responses was higher in the *COLOUR NEUTRAL* and *COLOUR INCONGRUENT* conditions than in the *COUNTING BACKWARD* condition in group 1 ($p_s<0.001$), group 2 ($p_s<0.001$) and group 3 ($p_s<0.001$). No difference was observed in adults ($p_s>0.29$). The performance of the *COUNTING BACKWARD* task was better in adults than in groups 1, 2 and 3 ($p_s<0.05$).

2.2. *Postural performance (see Figs. 2, 3 and Table 3)*

Results of the MANOVA showed a main effect of cognitive task ($F_{10,33}=3.53$, $p=0.003$) and crucially, a four-way interaction of age × gender × support surface × cognitive task ($F_{30,97}=16.8$, $p=0.03$). To determine which dependent variable accounted for the observed differences, ANOVAs were applied to each dependent variable. Statistical analysis of surface revealed a significant main effect of cognitive task ($F_{2,84}=11.65$, $p<0.01$) and crucially, a significant interaction of age × cognitive task ($F_{6,84}=2.30$, $p=0.042$). Groups 1 and 2 exhibited higher surface values in the *COUNTING BACKWARD* than in the *COLOUR NEUTRAL* conditions ($p_s<0.05$). Post hoc analysis revealed no significant differences between the cognitive tasks in group 3 and in adults (Figs. 2, 3 and Table 3).

Analysis of ML mean velocity and ML RMS revealed a significant main effect of cognitive task ($F_{2,84}=9.03$, $p<0.001$ and $F_{2,84}=8.37$, $p<0.001$, respectively). The interaction of age × cognitive task was significant for ML mean velocity ($F_{6,84}=3.01$, $p=0.01$) and ML RMS ($F_{6,84}=2.49$, $p=0.028$). Both were higher in the *COUNTING BACKWARD* than in the *COLOUR NEUTRAL* and *COLOUR INCONGRUENT* conditions for group 2, only ($p_s<0.05$). The ML RMS was also higher in the *COUNTING BACKWARD* than in the *COLOUR NEUTRAL* in group 1 ($p=0.007$).

Analysis of AP mean velocity and AP RMS just revealed a main effect of task ($F_{2,84}=8.63$, $p<0.001$ and $F_{2,84}=18.53$, $p<0.001$, respectively), with higher values in the *COUNTING BACKWARD* than in the *COLOUR NEUTRAL* and *COLOUR INCONGRUENT* conditions ($p_s<0.001$).

Additionally, the relationship between participants' height or weight and all postural variables was explored with a Spearman R correlation analysis. Results revealed that postural stability was not correlated with participants' height or weight ($p_s>0.05$).

3. Discussion

The purpose of the present study was to assess the attentional cost of postural control by determining the influence of a concurrent cognitive task on postural stability, in adolescents aged 12 to 17 years.

3.1. *Age-related differences in cognitive performances*

The number and percentage of correct responses did not vary between age groups, except in the *COUNTING BACKWARD* condition. Adults were faster and more accurate than adolescents at processing during the *COUNTING BACKWARD* task. Adleman et al. (2002) demonstrated that the development of executive processes involved in the Stroop interference still continued during adolescence. No similar study has been done for the counting task in teenagers. However, our results demonstrate that the performance in the backward counting task also improves after adolescence. The present results could be linked to the difference in attentional resources and working memory mobilized according to the nature of the cognitive task (Jamet et al., 2004). During a Stroop task, an interference phenomenon induced disturbance but not saturation in working memory implementation, whereas

Table 1 – P-values for the first, second and third order interactions of the ANOVAs.

	A	G	S	CT	A*G	A*S	A*CT	G*S	G*CT	S*CT	A*G*S	A*G*CT	A*S*CT	G*S*CT	A*G*S*CT
Surface area	0.22	1.00	0.48	<0.001*	0.76	0.61	.042*	0.99	0.10	0.34	0.62	0.13	0.36	0.31	0.70
ML mean speed	0.33	0.87	0.44	<0.001*	0.06	0.75	.010*	0.19	0.28	0.92	0.76	0.46	0.39	0.23	0.18
AP mean speed	0.32	0.91	0.18	<0.001*	0.17	0.50	0.12	0.79	0.14	0.39	0.12	0.28	0.23	0.32	0.70
ML RMS	0.16	0.62	0.90	<0.001*	0.81	0.97	.028*	0.76	0.49	0.12	0.19	0.20	0.24	0.08	0.15
AP RMS	0.57	0.90	0.27	<0.001*	0.74	0.08	0.37	1.00	0.08	0.57	0.42	0.09	0.31	0.26	0.53
NR	.004*	0.49	0.70	<0.001*	0.32	0.92	<0.001*	0.88	0.85	0.63	0.22	0.23	0.38	0.13	0.81

A = age.
G = gender.
S = support surface.
CT = cognitive task.
NR = number of responses.
*p<0.05.

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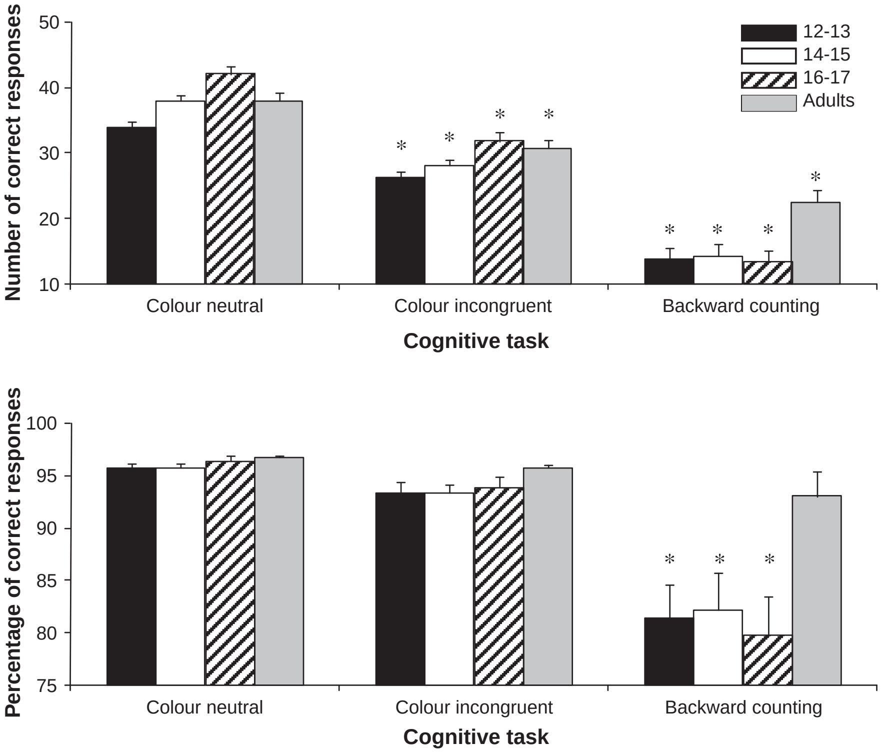

Fig. 1 – Number and percentage of correct responses in the three cognitive tasks (*COLOUR NEUTRAL*, *COLOUR INCONGRUENT* and *COUNTING BACKWARD*) for the adolescents and the young adults (means and standard errors). *p<0.05.

in a counting task, working memory rapidly reached the overload point (Lemaire et al., 1996). Such an overload may result in less efficient cognitive performances, especially in teenagers.

3.2. *Age-related differences in postural performances*

Results indicated larger CoP displacements in adolescents aged 14 to 15 years than in teenagers aged 16–17 years and in adults, regardless of the complexity of the postural tasks. Adolescence is a dynamic period of physiological and psychological transition. The period between 14 and 15 years is characterized by a degradation of postural orientation and body stabilization because of a transient neglect of proprioceptive cues (Viel et al., 2009). The present results confirmed the existence of a turning point at around 14–15 years when performing a dual task. The adults' level was reached at 16–17 years, only. Because of the body changes occurring during this period, the adolescents probably had to devote more attentional resources to the postural task.

Although body changes are markedly sexually dismorphic during pubertal development, the present results did not reveal any effect of gender on the cognitive and postural performances. Franchignoni et al. (1985) suggested that the developmental variations generally observed between genders did not influence the attentional resources allocated to

Table 2 – Number and percentage of correct responses (mean and standard error (SE)) for the cognitive tasks across age, gender and support surface.

Age	Gender	Colour neutral				Colour incongruent				Counting Backward			
		Firm mean	SE	Foam mean	SE	Firm mean	SE	Foam mean	SE	Firm mean	SE	Foam mean	SE
12–13	M	33.83	0.56	33.54	0.89	26.33	1.08	25.67	0.70	12.25	2.32	11.42	1.43
	F	33.94	1.39	34.89	1.25	26.50	1.29	27.11	0.98	16.72	1.90	16.11	3.54
14–15	M	36.72	1.45	37.44	0.95	28.78	1.32	28.61	1.81	15.11	4.04	17.33	3.60
	F	39.27	0.78	39.07	1.01	31.00	1.35	31.47	0.82	13.33	2.76	12.13	2.85
16–17	M	40.52	1.80	40.76	0.77	30.86	0.88	29.24	1.47	10.90	1.75	11.33	2.16
	F	43.47	2.08	44.80	2.07	34.60	2.81	34.07	2.84	15.60	2.58	16.93	3.50
Adults	M	39.25	1.18	39.04	1.43	30.96	1.34	32.08	1.24	22.83	1.89	23.46	2.25
	F	34.47	1.71	35.33	2.13	28.07	1.46	28.80	1.73	20.00	2.22	16.93	1.44

M = male.
F = female.

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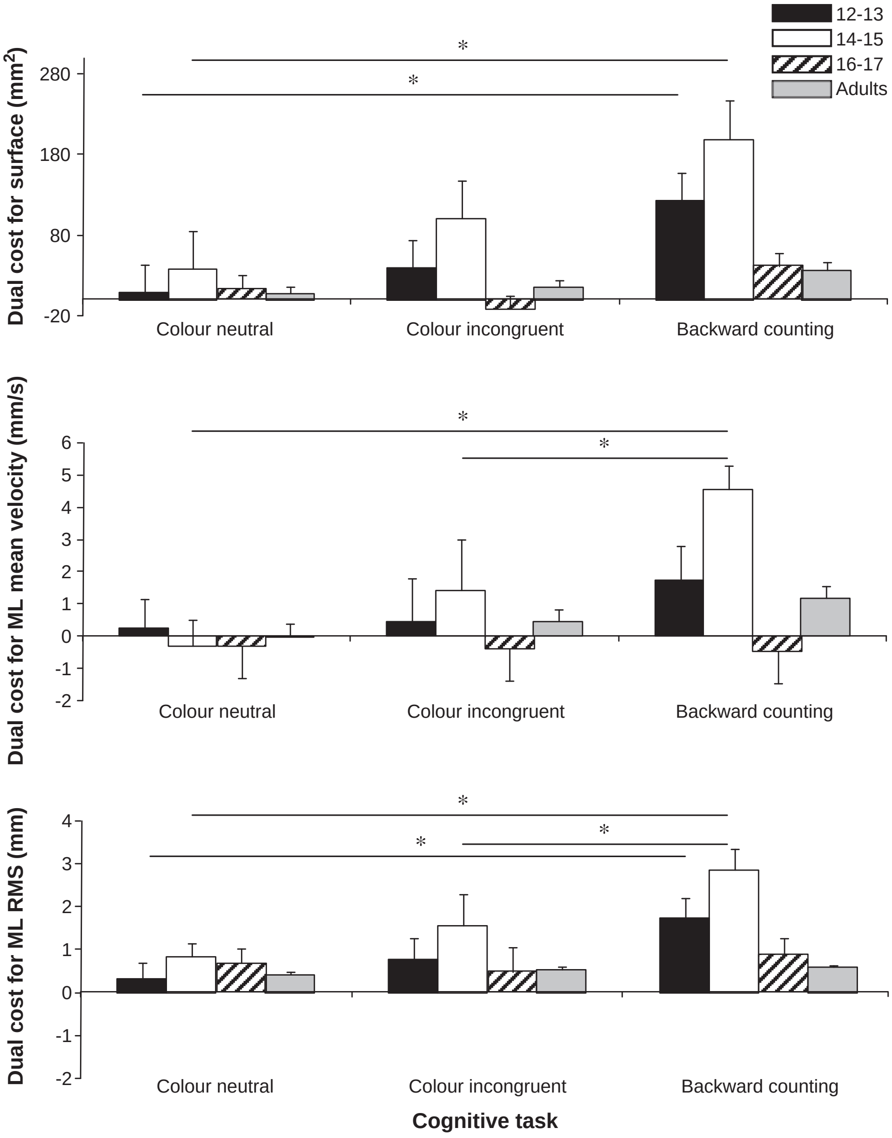

Fig. 2 – Evolution of the Dual Cost (i.e. difference between the *COLOUR NEUTRAL*, *COLOUR INCONGRUENT* or *COUNTING BACKWARD* and the *CONTROL* condition) of CoP surface area, ML mean speed and RMS for the adolescents and the young adults (means and standard errors). *$p<0.05$.

postural control. However, the differences between their protocol and ours (i.e., different age groups, no cognitive task, etc.) might explain the absence of gender effect in the present study. Moreover, Nolan et al. (2005) did not find a difference between genders after 10 years of age during single-task performance.

The assessment of growth in terms of height and weight showed no correlation between growth and postural control. Postural control may be partly affected by changes in stature as children grow. The development of the visual, vestibular, and somatosensory systems may account for age-related changes in balance control to a greater extent (Nolan et al., 2005). As in many development experiments, one limitation of this study is that individual level of maturation, as distinct from chronological age, was not measured. Adolescents develop at different rates and thus differences in balance due to maturation may have been missed. The use of both chronological and biological (e.g., skeletal maturation and dental development) ages would certainly lead to more precise results regarding the differences in dual-task performances between genders.

3.3. *Effect of postural task complexity on the cognitive and postural performances*

A general degradation of postural control was observed on the *foam* support surface whatever the age group and the concurrent cognitive task. These results are in accordance with several studies indicating that the postural task becomes more complex on a *foam* support surface than on a *firm* one and requires more attentional resources when the sensory cues decrease (Teasdale et al., 1993). We suggest that sufficient

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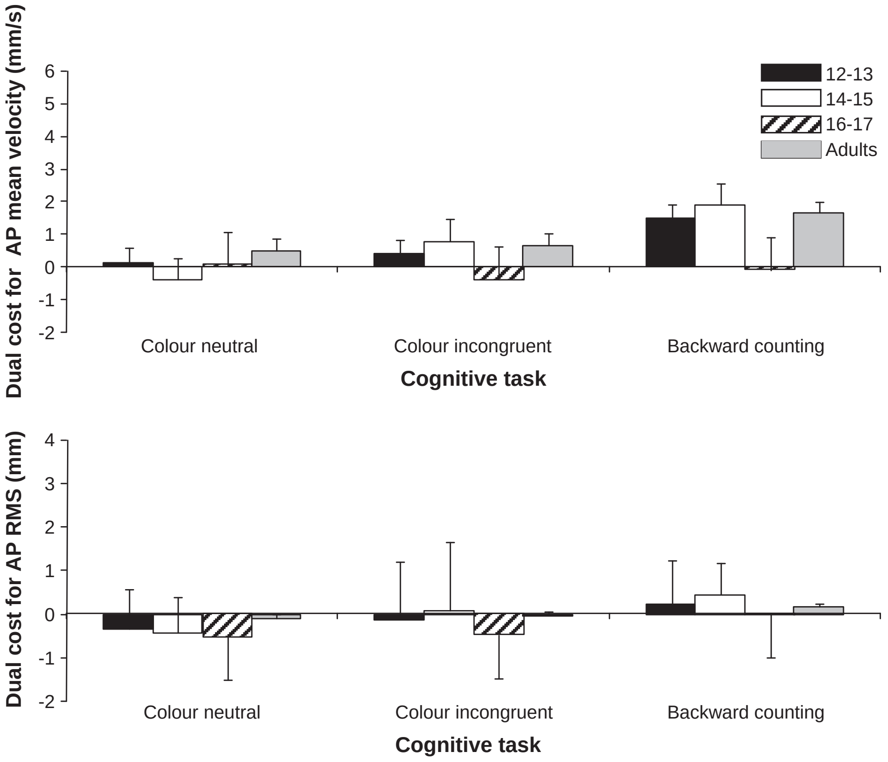

Fig. 3 – Evolution of the Dual Cost (i.e. difference between the *COLOUR NEUTRAL*, *COLOUR INCONGRUENT* or *COUNTING BACKWARD* and the *CONTROL* condition) of AP mean speed and RMS (means and standard errors). $^*p<0.05$.

resources were allocated to perform the cognitive task because the performance was not affected by postural task complexity.

When located on a firm base of support, healthy individuals rely mostly on somatosensory inputs but the dependence on these inputs decreases as the support surface becomes unstable (Peterka, 2002). This adaptive capacity of the central nervous system contributes to a more stable and flexible control of upright stance and already exists in children 4 to 10 years of age (Bair et al., 2007). As adolescents strongly rely on visual cues for body stabilization (Viel et al., 2009), they adapted to the degradation of proprioceptive information similarly to the adults.

3.4. *Effect of cognitive task complexity on cognitive and postural performances*

The increase of task complexity involved a smaller number of correct responses, suggesting that these three tasks did not require the same amount of attention in all groups. The *COUNTING BACKWARD* condition was particularly attentionally

Table 3 – Evolution of the Dual Cost (i.e. difference between the *COLOUR NEUTRAL*, *COLOUR INCONGRUENT* or *COUNTING BACKWARD* and the *CONTROL* condition) of the surface area (mean and standard error (SE)) for the cognitive tasks across age, gender and support surface.

Age	Gender	Colour neutral				Colour incongruent				Counting Backward			
		Firm mean	SE	Foam mean	SE	Firm mean	SE	Foam mean	SE	Firm mean	SE	Foam mean	SE
12–13	M	12.44	45.50	46.97	84.49	29.91	37.70	111.74	64.91	114.29	60.27	156.20	72.89
	F	23.95	52.54	−63.44	97.56	−9.59	43.53	6.23	74.95	79.37	69.59	135.57	84.17
14–15	M	30.07	52.54	96.97	97.56	103.12	43.53	−31.40	74.95	267.89	69.59	123.27	84.17
	F	−3.78	57.56	14.51	106.87	197.87	47.68	156.35	82.10	164.94	76.24	241.42	92.20
16–17	M	54.27	48.65	−90.73	90.32	−10.15	40.30	−84.76	69.39	83.56	64.43	30.71	77.93
	F	93.90	57.56	23.19	106.87	84.60	47.68	−10.49	82.10	5.41	76.24	35.68	92.20
Adults	M	−14.30	45.50	22.43	84.49	18.23	37.70	6.27	64.91	25.33	60.27	107.41	72.89
	F	36.36	57.56	−14.32	106.87	43.41	47.68	−3.82	82.10	−1.59	76.24	−20.87	92.20

M = male.
F = female.

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demanding in all groups and suggested – in accordance with Pellechia et al. (2003) – that an effective change in the level of difficulty actually occurred in adolescents and adults. The adults' cognitive performances were less affected than the teenagers'.

In Pellecchia's study (2003) with adults, the *COUNTING BACKWARD* task resulted in higher CoP path length, AP and ML excursions as compared to a digit reversal or classification task. This trend was also observed in children aged 8 to 10 (Blanchard et al., 2005). The present study demonstrates a similar result between 14 and 15 years of age. We did not find an increase of CoP displacements for the *COUNTING BACKWARD* task in adults as Pellechia (2003) did. The different protocols (i.e. baseline condition and postural task) might be an explanation. The absence of interaction between age group and task on the AP axis might be simply due to the semi-tandem position that involved an increase of the base of support on the AP axis and a decrease of this base of support on the ML axis. As the task prioritization model postulates that subjects always prioritize postural control over cognitive activity under specific conditions (i.e., postural threat conditions), this model is not valid for the present experiment. The cross-domain competition model, which speculates that there is a limited attentional and processing capacity in humans, can explain the dual-task interference observed in teenagers aged 12 to 15 years, particularly in the *COUNTING BACKWARD* task. Participants had to divide their attentional resources to perform both tasks simultaneously. This *COUNTING BACKWARD* task required much more attentional resources than the other two cognitive tasks (*COLOUR NEUTRAL* and *COLOUR INCONGRUENT*). As a result, fewer resources were available for postural control while performing the *COUNTING BACKWARD* task. It resulted in a degradation of balance performance. The difference in dual-task performance between groups might be due to 1) difficulties in properly allocating attentional resources to both tasks (i.e., the completion of the mathematical task may have shifted the teenagers' prioritization from the postural to the cognitive task) and, 2) the inability to manage increased requests because of a limited information processing capacity (i.e., the capacity was exceeded in adolescents aged 14–15 years). This capacity might still be under development in teenagers aged 14 to 15 years.

In summary, the present results confirmed the existence of a turning point in postural control around 14–15 years of age while performing a dual task, whatever the gender. The performance of a concomitant cognitive task (i.e. Stroop or counting backward task) resulted in higher CoP displacements in adolescents aged 14 to 15 years than in teenagers aged 16 to 17 years and in adults. Increased difficulty of the postural task did not modify performances in the Stroop and the counting backward task.

4. Experimental procedure

4.1. *Participants*

37 adolescents aged 12 to 17 years and 13 young adults (8 men and 5 women; mean age = 26.1 years old ± 4.3 years; mean height = 175 ± 9 cm; mean weight = 64.3 ± 8.1 kg) participated. The adolescents were divided into three age groups: group 1 was 12–13 years old (N = 14; 8 boys and 6 girls; mean age = 12.9 - years old ± 0.7; mean height = 159 ± 12 cm; mean weight = 45.6 ± 11.4 kg), group 2 was 14-15 years old (N = 11; 6 boys and 5 girls; mean age = 14.8 years old ± 0.6; mean height = 166 ± 7 cm; mean weight = 53.4 ± 9.7 kg) and group 3 was 16–17 years old (N = 12; 7 boys and 5 girls; mean age = 17.1 years old ± 0.5; mean height = 176 ± 10 cm; mean weight = 67.4 ± 10.5 kg). The experiment was undertaken with the written consent of each participant or their parents as required by the Helsinki declaration (1964). All participants were naive to the purpose of the experiment. They were recruited on a voluntary basis and were schoolboys/girls with a normal scholastic level. None of the participants exhibited any known neurological disorder.

4.2. *Task and procedures*

Participants stood barefoot on a force platform (Equi+, model PF01, Aix les Bains, France) in a semi-tandem position with the right foot in front of the left one and 3 cm apart on the mediolateral axis. A dual-task paradigm, in which participants performed a Stroop or a backward counting task simultaneously with a quiet standing task on a firm or foam support surface, was used to determine the attentional demand of postural control in adolescents.

4.2.1. *Postural task*

Participants were asked to sway as little as possible on a *firm* or a *foam* support surface. The force platform corresponded to the *firm* support surface. A 2-cm thick foam was placed between the force platform and participants' feet in the *foam* condition in order to decrease the reliability of the somatosensory contribution to postural control. The support surface was altered to determine whether additional attentional resources needed to be allocated to the postural task when there was a reduction of the available sensory inputs.

4.2.2. *Cognitive task*

Participants were asked to respond as quickly as possible while standing on the force platform. A control condition and three cognitive tasks were performed. In the control condition, participants fixated a point located at the centre of a white 15″ screen that was placed 1.5 m in front of them and repeated aloud in the following order "blue", "white" and "red" at a rate of approximately 60 words per minute (*CONTROL* condition). This condition was used as a baseline condition instead of the traditional "standing still" condition because comparing performances between a dual and a single task is problematic. In the "standing still" condition, the experimenters have no control over what participants are thinking about and the only task load is dedicated to postural control (Fraizer and Mitra, 2008). Moreover, verbal answers produce changes in postural stability that are unrelated to the cognitive load (Dault et al., 2003; Yardley et al., 1999): it is thus more appropriate to compare dual tasks that require the same physical response, such as articulation.

The first cognitive task was a computerized version of the Stroop test in which participants were instructed to name the colour of bars (red, blue, yellow or green) that appeared on the

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same 15″ monitor screen as quickly and as accurately as possible (*COLOUR NEUTRAL* condition).

The second cognitive task was another computerized version of the Stroop test in which participants were required to name the colour of incongruent colour words as quickly and as accurately as possible (*COLOUR INCONGRUENT* condition). The distractor provided by the word generally leads to slower responses and more errors than the *COLOUR NEUTRAL* condition (Stroop, 1935), especially in 7-year-old children (Olivier et al., 2007; Tipper et al., 1989). The bars or the words were always presented one by one on the screen and the following bar or word was immediately presented once participants had responded.

The last cognitive task involved participants counting backward by steps of 3 (*COUNTING BACKWARD* condition). Participants had to count loud from a random number of two digits given by the experimenter. This task has been already used by Pellecchia (2003) and Blanchard et al. (2005) and was classified as particularly attention demanding.

Prior to data collection, participants practiced the four different tasks for a minimum of 15 s each. Three 32 s trials with 15 s of standing rest in-between were then performed in each condition (64 Hz sampling frequency). All trials started with a fixation point at the centre of the screen. The control and cognitive tasks were presented randomly among participants in order to rule out sequence effects. The total number of items and errors in the *COLOUR NEUTRAL*, *COLOUR INCONGRUENT* and *COUNTING BACKWARD* conditions were recorded for each 32 s trial. Participants were instructed to perform the postural and cognitive tasks as efficiently and as accurately as possible.

4.3. *Dependent variables*

4.3.1. *Postural performance*

Five CoP measures were calculated: the 90% confidence ellipse area (surface in mm^2), the mean velocity (in $mm.s^{-1}$) on the antero-posterior (AP) and medio-lateral (ML) axes, the AP and ML root mean square (AP RMS and ML RMS in mm). The surface area is a good measure of CoP spatial variability (Vuillerme et al., 2008). The mean speed represents a good index of the amount of neuromuscular activity required to regulate postural control (Geurts et al., 1993). The AP and ML RMS enable us to estimate overall postural performance. The reliability and validity of these parameters for the clinical quantification of postural control has been already demonstrated (Geurts et al., 1993; Piirtola and Era, 2006; Pinsault and Vuillerme, 2009). A reduction of at least one of these postural parameters has often been considered as an improvement of postural stability (Vuillerme et al., 2008).

4.3.2. *Cognitive performance*

In the three cognitive tasks, the number (cognitive index of speed) and the percentage (cognitive index of accuracy) of correct responses were calculated with respect to the total number of items performed in each task.

4.4. *Statistical analysis*

Since the five postural variables may be partially correlated, an ages (12–13, 14–15, 16–17 and *adults*) × 2 genders (*male* and *female*) × 2 support surfaces (*firm* and *foam*) × 3 cognitive tasks (*COLOUR NEUTRAL*, *COLOUR INCONGRUENT* and *COUNTING BACKWARD*) multivariate analysis of variance (MANOVA) with repeated measures on the last two factors was applied to postural data. A 4 ages (12–13, 14–15, 16–17 and *adults*) × 2 genders (*male* and *female*) × 2 support surfaces (*firm* and *foam*) × 3 cognitive tasks (*COLOUR NEUTRAL*, *COLOUR INCONGRUENT* and *COUNTING BACKWARD*) analysis of variance (ANOVA) with repeated measures on the last two factors was applied to each postural variable. The purpose of the ANOVA was to determine whether in adolescents the attentional demand of postural control was influenced by the performance of a concurrent cognitive task while swaying on different support surfaces. Adjustments of the p-values for the violation of the sphericity assumption were made using a multivariate test (Hotelling-Lawley Trace) and post hoc analyses (Tukey HSD) were used whenever necessary. In addition, Spearman R correlations were calculated to assess whether postural performance was correlated to participants' weight and height.

Another 4 ages (12–13, 14–15, 16–17 and *adults*) × 2 genders (*male* and *female*) × 2 support surfaces (*firm* and *foam*) × 3 cognitive tasks (*COLOUR NEUTRAL*, *COLOUR INCONGRUENT* and *COUNTING BACKWARD*) ANOVA with repeated measures on the last two factors was applied to the number and percentage of correct responses, to compare the cognitive performance among the *COLOUR NEUTRAL*, *COLOUR INCONGRUENT* and *COUNTING BACKWARD* cognitive tasks. For all ANOVAs, the level of significance was set at $\alpha < 0.05$.

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