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INTRODUCTION

Phasic attention and alert task

1 Phasic attention refers to the capacity to "prepare for" an imminent event. This component of attention is under voluntary control and involves mobilization of resources to process the expected stimuli (Nebes & Brady, 1993). The "prototypal" paradigm to request phasic attention consists of providing a warning signal (or alert) before presentation of a target to which the participant gives a simple detection response. The warning signal indicates to the participant that a target will occur but provides no information about the target. In order to make target presentation unpredictable (thereby reducing anticipation), Stimulus Onset Asynchrony (SOA) is always used when a simple detection response is required. Alerting involves a change in the internal state that follows presentation of the warning signal which accelerates detection of the subsequent target (Fernandez-Duque & Posner, 1997). Phasic attention capacity is estimated by comparing reaction time (RT) obtained for alert trials and for trials without alert (or control trials). Typically, alert impacts on RTs by accelerating responses compared to control trials.

2 To date, the temporal aspects of phasic attention have been assessed by analyzing the effect of SOA duration. To the best of our knowledge, the effect of SOA has never been evaluated in studies conducted in children and in only two studies conducted in adults.

Fernandez-Duque and Posner (1997) reported that the alert effect was enhanced as SOA duration increased (100, 700 and 1400 ms) in young adults. In contrast, Nebes and Brady (1993) reported that the alert effect increased as SOA increased up to a value of 300 ms in young and elderly adults. Beyond 300 ms, the alert effect decreased as SOA increased (SOAs used in this study were: 50, 100, 150, 300, 600 and 1000 ms). These results suggest that phasic attention: (i) needs time to build up and hence only becomes effective after a given period, and (ii) could reach an optimal level at a particular time-point beyond which phasic attention becomes less efficient.

Development of phasic attention during childhood

3 Very few studies have been devoted to the maturation of phasic attention. Rueda, Fan, McCandliss et al. (2004), using the Attention Network Test (ANT), reported that children aged 6 to 10 years benefited from alert with no major differences between age-groups. In this study, developmental changes in alerting were observed between 10-year-old children and adults. Ridderinkhof, van der Molen, Band and Bashore (1997) assessed alertness by comparing fixed and variable warning intervals preceding presentation of the target. Fixed foreperiods led to faster mean RTs than variable periods, but this effect was independent of age from 5 to 21 years. However, responses to the target in these two studies did not consist of simple detection, but required a decision between two distinct stimuli (participants performed a flanker task in both studies). The temporal dynamics of alertness were not examined in these studies. Drechsler, Brandeis, Foldenyi, Imhof and Steinhausen (2005), using a pure simple detection task, reported a longitudinal effect of RT from 10.8 to 12.0 years and from 12.0 to 13.3 years. Mean RT decreased with increasing age, but the alert effect was independent of age (a similar amplitude of the alert effect was observed in all age-groups). The effect of variations of SOA duration was not analyzed in this study. The results reported in these three studies suggest that phasic attention could be mature in 5-year-old children, although global speed continues to improve after the age of 6 years.

The present study

4 This paper focuses on the temporal aspect of phasic attention in children aged 6 to 10 years. This question was addressed by using a simple reaction time task during which the targets were presented alone or preceded by an alert signal. The SOA between alert and target (both visual) was manipulated by means of three distinct durations: 100, 450 and 800 ms. Firstly, the temporal dynamic was assessed by a classical analysis taking into account the impact of the SOA duration on the alert effect. Secondly, delta plot analysis was applied to the alert task. This method, previously applied to a flanker task by Ridderinkhof, Scheres, Oosterlaan and Sergeant (2005), uses a distributional analytical technique which takes into account the effect of a manipulated experimental factor as a function of the reaction time distribution. As shown by Ridderinkhof et al. (2005), this method appears to be highly sensitive to the temporal aspects of cognitive processes and can be used to estimate the time required by the processes to build up (see also for an application of this method to a stroop task: Bub, Masson, & Lalonde, 2006).

5 Responses to experimental tasks become faster with increasing age during childhood (for example, this is the case for stop signal, flanker or saccade tasks: Bedard, Nichols,

Barbosa, Schachar, Logan, & Tannock, 2002; Davis, Segalowitz, & Gavin 2004; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Williams, Ponesse, Schachar, Logan, & Tannock, 1999. In terms of global parameters, the decrease of mean RT and RT variability with increasing age was expected, as previously observed for alert tasks (Drechsler et al., 2005; Ridderinkhof et al., 1997; Rueda et al., 2004). Acceleration of responses concerned not only sensory-motor processes but also higher cognitive processes such as inhibitory processes engaged to suppress proponent motor responses, as the time required to stop proponent motor responses decrease with increasing age during childhood and adolescence (Bedard et al., 2002; Williams et al., 1999). According to Rueda et al. (2004) and Ridderinkhof et al. (1997), all children aged 6 to 10 years derive a fairly similar benefit from alert. However, maturation of the temporal dimension in alert processing has not yet been studied. As shown previously for inhibitory processes engaged to suppress proponent motor responses, the time required for the alert to become effective decreases with age. We therefore hypothesised that children should benefit from alert with a shorter SOA duration in older children than in young children. A concave-downward function was expected for the distributional effect of alert. In the first half of the response distribution, erroneous responses to the warning signal may be reflected by an "apparent alert effect" decreasing up to the time-point where the alert effect started to be observed. Beyond this time-point, a marked acceleration effect, increasing as a function of response time, was expected. Maturation of phasic attention should be reflected by a more pronounced slope with increasing age.

METHOD

Participants

6 The children were selected from mainstream schools in the city of Amiens in northern France. The children's parents received comprehensive information on the study and its objectives. Parents and children willing to participate in the study signed an informed consent form. The study was approved by the Amiens local ethics committee. Semistructured interviews were conducted with the teachers of children who participated in the study. On the basis of the teacher's replies and questionnaires completed by the parents, all children in whom learning disabilities, dyslexia, developmental coordination disorder, attention deficit hyperactivity disorder, conduct disorder, neurological or psychiatric disorder were suspected and all children with acute or chronic illness were excluded from the study. All children attended regular schools and showed normal levels of academic achievement. None exhibited learning difficulties or behavioural disorders. The following exclusion criteria were applied: a history of neurological or psychiatric disorders, sensory-motor deficits or learning difficulties. IQ was individually estimated by administering four subtests (Vocabulary, Similarities, Block Design and Picture Completion) of the *Wechsler Intelligence Scale for Children* (3rd ed.; *WISC-III*). This short form of WISC correlates with the full-scale IQ at .90 (Kaufman, Kaufman, Balgopal, & McLean, 1996).

7 Finally, 96 French-speaking children (46 girls and 50 boys), aged from 6 to 10 years (mean: 8.6; range: 6.0 to 10.9) with an IQ score of 70 or higher (mean: 106.6; S.D., 19.8) were included in the study (for demographic and psychometric data, see Table 1).

	Demographic data			Age			WISC-III	
	N	Girls	Boys	Mean	(S.D.)	[min – max]	Mean	(S.D.)
6-years	17	10	7	6.46	(0.28)	[6.0 - 6.9]	106.6	(17.5)
7-years	19	9	10	7. 46	(0.34)	[7.0 - 7.9]	109.2	(19.5)
8-years	17	8	9	8. 46	(0.31)	[8.0 - 8.9]	103.6	(24.7)
9-years	19	8	11	9.44	(0.25)	[9.0 - 9.9]	102.2	(16.9)
10-years	24	11	13	10.55	(0.29)	[10.0 - 10.9]	110.1	(20.4)

Table 1: Demographic data and WISC-III scores for each group of children (6-years / 7-years / 8-years / 9-years / 10-years).

Stimuli and apparatus

8 Participants were seated 60 cm in front of a 17” color screen and responded via the space bar of the computer. The task was run using SuperLab software (Cedrus Corporation). A black cross placed in the center of a white square with a black contour was displayed at the center of the screen and served as a fixation mark (cross: 0.5 cm per side, 0.5° visual angle; square: 2 cm per side, 2° visual angle). The target was a red asterisk (*) displayed at the site of the fixation mark (asterisk: diameter of 1.5 cm, 1.5° visual angle). The alert consisted of circling the square for 33 ms.

Task and procedure

9 Children were instructed to fix their eyes on the central marker and to press the space bar as soon as the target appeared in the square. Children were informed that a warning signal would precede the target in one half of trials. In all trials, the target was preceded by the fixation mark for 1100 ms, 1450 ms or 1800 . In alert trials, the target was preceded by the alert with an SOA of 100 ms, 450 ms or 800 ms. A new trial started when the response bar was pressed or after a 1500 ms delay without response. The experiment consisted of 6 blocks in which 4 trials per condition were randomized by block. The task was composed of 144 trials (24 trials per condition plus 12 training trials) and lasted a total of about 7 minutes.

OVERALL PERFORMANCE

Statistical design and analysis

10 Response times less than 100 ms after target presentation wemsre excluded from RT analyses. ANOVAs were run on the mean RTs and RT-variability (estimated by the intra-individual standard deviation (SD) of RTs), while taking into account the alert effect (alert trial / control trial) and SOA (SOA-100 ms / SOA-450 ms / SOA-800 ms) as a within-subject factor, and age-group as a between-subject factor (6 years / 7 years / 8 years / 9 years / 10 years). A Duncan test was used for *post hoc* comparisons (Level of significance for ANOVAs and *post hoc* analysis: $p < 0.05$).

11 The effect size of age-group on mean age was very large [$F(4, 91) = 297$, $p < 0.0001$, $\eta_p^2 = 0.96$]. *Post hoc* analysis showed that mean age was significantly different between each group of children ($p < 0.0001$ for each comparisons) (see, for details of mean age and S.D. per group: Table 1). Mean age, number (N) and estimated IQ of the children of each age-

group were as follows: 6 years [mean age: 6.5, N: 17, IQ: 106.6], 7 years [mean age: 7.5, N: 19, IQ: 109.2], 8 years [mean age: 8.5, N: 17, IQ: 103.6], 9 years [age: 9.4, N: 19, IQ: 102.2] and 10 years [mean age: 10.6, N: 24, IQ: 110.1]. IQ presented a homogeneous distribution between all age-groups (age-group was not a significant factor: [F(4, 91) = 0.6, p = 0.67, η_p^2 =0.025]).

Results of overall performances

12 Mean RT (see Figure 1 and Annex 1). The effect size of age-group on RT was large with RT decreasing as a function of age [F(4, 91) = 10.5, p < 0.0001, η_p^2 = 0.32]: 456±74 ms at 6 years, 403±73 ms at 7 years, 358±73 ms at 8 years, 348±74 ms at 9 years and 328±53 ms at 10 years. RT decreased significantly between the age of 6 and 7 years (p = 0.020) and between the age of 7 and 8 years (p = 0.049). Although RT continued to decrease after 8 years, this difference was no longer statistically significant (RT differences were not significant between 8 and 9 years, 8 and 10 years, and 9 and 10 years). However, it cannot be concluded that optimal RT was reached by the 8-year-old group due to the lack of statistical power between the older groups (*W* = 0.55, 0.43, 0.07 and 0.17 between 6 and 7-years; 7 and 8-years, 8 and 9-years; and between 9 and 10-years groups, respectively).

13 A large effect size of alert was observed on RT [F(1, 91) = 17.9, p = 0.00056, η_p^2 = 0.17]: independently of age and SOA, responses were faster for alert (369±83 ms) than for control trials (380±82 ms). The SOA duration exhibited a very large effect size on RT independently of trials and age [F(2, 182) = 226.0, p < 0.0001, η_p^2 = 0.71]: RTs decreased as function of SOA duration: 418±96, 363±81 and 344±74 ms for SOA of 100, 450 and 800 ms, respectively (p < 0.0001 for each comparison). Globally, alert and SOA duration clearly impacted on RT by accelerating responses (η_p^2 = 0.17 for alert and η_p^2 = 0.71 for SOA). However, the impact of alert on RT depended on the SOA duration. The alert effect interacted significantly with SOA duration [F(2, 182) = 14.5, p < 0.0001, η_p^2 = 0.14]: RTs were faster for alert trials than for control trials for SOA durations of 100 ms (406±95 and 429±101 ms, respectively, p < 0.001) and 800 ms (339±77 and 348±76 ms, respectively, p = 0.012), but were fairly similar for alert and control trials for an SOA duration of 450 ms (363±86 and 362±80 ms, respectively).

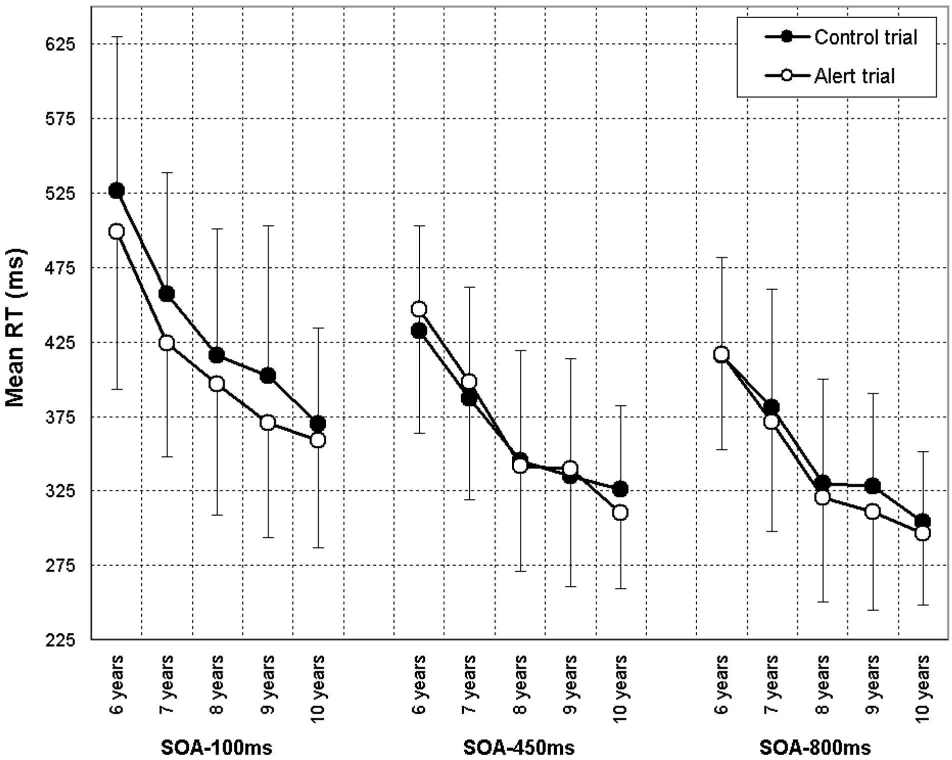

Figure 1: Mean RT as a function of alert (Alert trial / Control trial), SOA (100ms / 450ms / 800ms) and age-group (6 years / 7 years / 8 years / 9 years / 10 years).

14 Finally, the interaction between Age, SOA and Alert reached significance and showed a medium effect size on RT [$F(8, 182) = 2.0$, $p = 0.046$, $\eta_p^2 = 0.082$]. In order to reduce the risk of family-wise type-I errors, ANOVAs were run separately for each age-group with Alert and SOA as within-subject factors. A principal effect of SOA duration was found in all age-groups (speed increased significantly as function of SOA duration in all age-groups) ($p < 0.0001$ for all comparisons). In 6-year-old children, the difference between RT in alert and control trials was not statistically significant (-27±65 ms, +12±46 ms and +1±49 ms for SOA durations of 100, 450 and 800 ms, respectively). In 7-year-old children, response times were significantly faster in alert trials than under control conditions only for an SOA duration of 100 ms (-33±31 ms with $p = 0.00018$, +11±31 ms and -10±38 ms for SOA durations of 100, 450 and 800 ms, respectively). In 8-year-old children, responses were significantly faster in alert trials than in control trials for SOA durations of 100 and 800 ms (-20±36 ms with $p = 0.041$, -3±27 ms and -10±20 ms with $p = 0.062$ for SOA durations of 100, 450 and 800 ms, respectively). As in 8-year-old children, response times were significantly faster in 9-year-old children in alert trials than in control trials for SOA durations of 100 and 800 ms (-31±44 ms with $p = 0.0059$, +5±34 ms and -18±18 ms with $p = 0.013$ for SOA durations of 100, 450 and 800 ms, respectively). In 10-year-old children, response times were significantly faster in alert trials than in control trials only for an SOA duration of 450 (-11±32 ms, -15±29 ms with $p = 0.013$ and -8±28 ms for SOA durations of 100, 450 and 800 ms, respectively).

15 In summary, responses for the SOA duration of 100 ms were significantly faster in alert trials than in control trials in all age-groups except for 6-year-old and 10-year-old children for which the alert effect was similar to that observed in other age-groups, but was not statistically significant. For the SOA duration of 450 ms, response times were

faster in alert trials than in control trials only in 10-year-old children (the alert effect was not statistically significant in all other age-groups). Finally, for the SOA duration of 800 ms, response times were faster in alert trials than in control trials only in 8- and 9-year-old children (the alert effect was not statistically significant in all other age-groups including 10-year-old children).

16 Mean SD (see Figure 2 and Annex 2). Age had a large effect size on mean RT variability [F (4, 91) = 12.0, p < 0.0001, η_p^2 = 0.35]: 163±49 ms at 6 years, 117±28 ms at 7 years, 98±31 ms at 8 years, 104±46 ms at 9 years and 85±29 ms at 10 years (p = 0.00038 between 6-year-olds and other age-groups, p = 0.016 between 7 and 10 years, no other significant difference was observed). RT variability decreased from 6 to 8 years and reached an asymptotic level around 7-8 years in our population of children. However, statistical power may have been insufficient to reveal significant differences for SD between 8, 9 and 10 years: (*W* = 0.93 between 6 and 7-years; *W* = 0.46 between 7 and 8-years groups; *W* = 0.07 between 8 and 9-years; *W* = 0.36 between 9 and 10-years groups). Age interacted significantly with Alert for SD [F(4, 91) = 4.2, p = 0.0036, η_p^2 = 0.16]. The planned comparisons indicated that variability was greater in alert trials than in control trials at 6 years [F(1, 91) = 5.3, p = 0.025, η_p^2 = 0.15], and was decreased in alert trials than in control trials at 7, 8, 9 and 10 years ([F(1, 91) = 8.5, p = 0.0046, η_p^2 = 0.29], [F(1, 91) = 5.3, p = 0.024, η_p^2 = 0.27], [F(1, 91) = 3.3, p = 0.074, η_p^2 = 0.24] and [F(1, 91) = 4.7, p = 0.034, η_p^2 = 0.22], respectively). The effect size of the alert factor was medium at 6 years and was large for all other age classes.

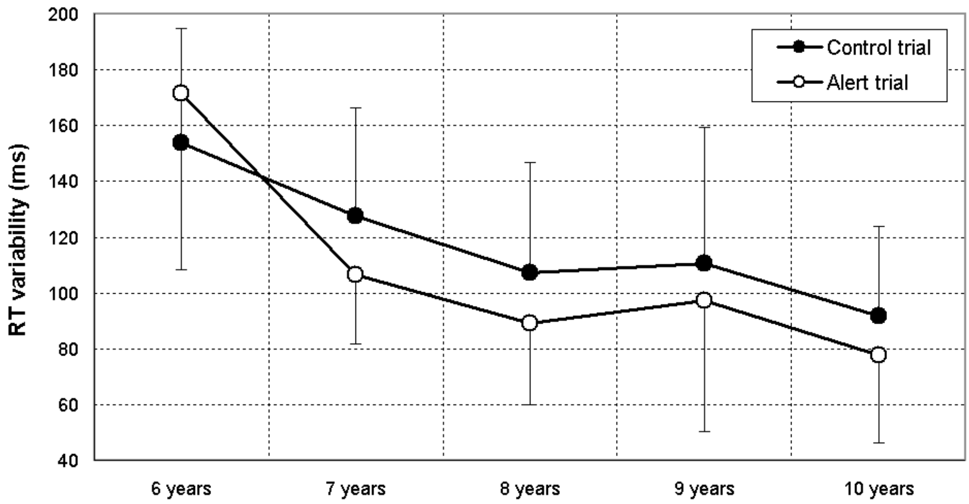

Figure 2: Variability (intra-individual SD) as a function of alert (Alert trial / Control trial) and age-group (6 years / 7 years / 8 years / 9 years / 10 years).

17 Omissions (see Annex 3). A large effect size of age-group on the rate of omissions was found [F(4, 91) = 9.3, p < 0.0001, η_p^2 = 0.29]. Omissions decreased as a function of age: 1.18 ±1.55 ms at 6 years, 0.07±0.22 ms at 7 years, 0.12±0.37 ms at 8 years, 0.007±0.07 ms at 9 years and 0.03±0.14 ms at 10 years (p < 0.0001 between 6-year-olds and other age-groups, while other comparisons were not significant). The alert factor had a negligeable effect on the rate of omissions [F(1, 91) = 0.0, p = 0.87, η_p^2 = 0.00]. The Age-SOA interaction showed a medium effect size on the rate of omissions [F(8, 182) = 2.6, p = 0.011, η_p^2 = 0.10]. Children of the 6-year-old group made significantly more omissions for SOA-100 (1.96 ±3.33) than for SOA-450 (1.10±1.67; p = 0.0026) and more omissions for SAO-450 than for SOA-800 (0.49±0.91, p = 0.031). For SOA-100, omissions were significantly more frequent in

the 6-year-old group (1.96±3.33), than in the 7-year-old group (0.22.±0.66, $p < 0.0001$), 8-years-old group (0.12±0.51, $p < 0.0001$), 9-years-old group (0.11±0.48, $p < 0.0001$), and 10-year-old group (0.00±0.00, $p < 0.0001$) (all other comparisons were not significant). For SOA-450, omissions were significantly more frequent in the 6-year-old group (1.10±1.67), than in the 7-year-old group (0.00.±0.00, $p = 0.016$), 8-year-old group (0.00±0.00, $p = 0.018$), 9-year-old group (0.00±0.00, $p = 0.017$), and 10-year-old group (0.09±0.43, $p = 0.024$) (others comparisons were not significant). For SOA-800, omissions were not significantly different in the 6-years group (0.46±0.91), and in the 7-year-old group (0.00.±0.00), 8-year-old group (0.25±0.69), 9-year-old group (0.11±0.48), and 10-year-old group (0.09±0.43) (others comparisons were not significant).

Discussion of overall performances

18 In agreement with previous results obtained in children performing an alert task (Drechsler et al., 2005; Ridderinkhof et al., 1997; Rueda et al., 2004) and stop signal, flanker, or saccade tasks (Bedard et al., 2002; Davis et al., 2004; Luna et al., 2004; Williams et al., 1999), mean response time and variability decreased significantly with age. Previous studies have shown that the asymptotic speed level was reached around the age of 12-13 years for flanker task (Davis et al., 2004), 14-15 years for saccade tasks (Luna et al., 2004), and 13-17 years for go-response during the stop signal task, but the optimal latency in stop-signal RT was not reached until the age of 18 (Bedard et al., 2002; Williams et al., 1999). In the present study, speed and variability of response improved dramatically until 8 years. After 8 years, the slight decrease of mean RT and variability was not significant. This result could indicate that an asymptotic speed level was reached at 8-9 years but the statistical power for mean RT and variability between groups older than 8 was not sufficient to reach a statistically significant conclusion. However, in line with previous developmental studies (Bedard et al., 2002; Davis et al., 2004; Luna et al., 2004; Rueda et al., 2004; Williams et al., 1999), improvement of speed and variability with increasing age was more pronounced for young children than for adolescents.

19 Response time decreased dramatically as a function of SOA duration in all age-groups. This result indicated that children responded more rapidly to the target when they had more time to prepare their response. The SOA duration also impacted on the alert effect. Firstly, a marked principal effect of SOA duration on alertness was observed. Response times were fairly similar in alert trials and control trials for a SOA duration of 450 ms, while response times where significantly faster in alert trials than control trials for SOA durations of 100 and 800 ms. The fact that an alert shortened response time for an SOA duration of 800 ms but not for an SOA duration of 450 ms was consistent with the concept that alertness requires a certain amount of time to be efficient. On the other hand, the fact that response times were faster in alert trials than in control trials for a SOA duration of 100 ms appears to be in contradiction with the previous statement. We suggest that this apparent alert effect found for the shortest SOA duration did not reflect an alert effect of the warning signal on detection of the target, but indicates that many erroneous responses were given to the alert, rather than to the target. This result is concordant with the finding that adults exhibited a weak alert effect for SOA durations around 100 ms (Fernandez-Duque & Posner, 1997; Nebes & Brady, 1993).

20 According to our hypothesis, the impact of SOA duration on alertness differed as a function of age. Considering only SOA durations of 450 and 800 ms for which the alert

effect can be supposed to be weakly affected by erroneous responses to the alert: (i) 6-7-year-old children had difficulties correctly using the warning signal for these two SOA durations, (ii) 8-9-year-old children benefited from the alert only for the longest SOA duration, and (iii) only 10-year-old children benefited from alert for the SAO duration of 450 ms, an effect that appeared to decline for the longest SOA duration in this group. This result confirmed our hypothesis that the time required for alert to become effective decreased with increasing age during childhood. The decline of the alert effect from SOA durations of 450 ms to 800 ms in older children suggested that phasic attention could reach an optimal level at a specific time after which phasic attention became less efficient. A similar observation has been reported in adults by Nebes and Brady (1993). These authors reported that the alert effect increased regularly from SOA durations of 50 to 300 ms and declined after this time-point.

DISTRIBUTIONAL ANALYSIS

Statistical design and analysis

21 As described by Ridderinkhof et al. (2005), response times were divided into time-ordered quintiles for alert trials (AT) and for control trials (CT) for each participant. Delta plots for RT were constructed by plotting the magnitude of the alert effect (mean RT in AT minus mean RT in CT, per quintile) against response time (mean RT in AT and CT per quintile from Q1 to Q5).

22 Slopes were computed for the delta-RT segments by connecting the data points for quintiles Q1 & Q2, Q2 & Q3, Q3 & Q4, and Q4 & Q5. An ANOVA was run on the mean slope, with age-group as between-subject factor, to estimate the alert effect as a function of response time. A set of ANOVAs was run on the slope of each of the delta plot segments (Q1/2, Q2/3, Q3/4, Q4/5) for RT with age-group as between-subject factor. A Duncan test was used for *post hoc* comparisons (Level of significance: $p < 0.05$).

Results of distributional analysis

23 Delta plot for RT (see Figure 3 and Annex 4). Two alert effect patterns as a function of RT distribution were distinguished. Firstly, in 6-year-old children, the slope was globally flat between Q1 and Q4 and became strongly positive in the last segment. Response times were faster for alert trials than for control trials from Q1 to Q4 (differences of -15±38, -8 ±22, -14±26 and -10±37 ms, respectively) but were longer in the last quintile Q5 (difference of +27±101 ms). This pattern was opposite to that expected for alertness, as, compared to control trials, alert was expected to accelerate response times at the end of the RT distribution (from the time-point when phasic attention started to be operant). Secondly, in 7- to 10-year-old children, slopes were flat or weakly positive in the first segment of the RT distribution, and became negative from Q2. After Q2, the slopes became more markedly negative as RT increased (RT differences between alert and control trials from Q1 to Q5 were as follows: +2±30, +3±14, -3±17, -12±26 and -42±71 ms respectively in 7-year-old children; -4±17, +2±15, +1±17, -8±19 and -40±55 ms, respectively in 8-year-old children; -16±28, -1±15, -4±25, -9±25 and -41±54 ms respectively in 9-year-old children; -9±25, +4±13, +1±15, -7±18 and -43±49 ms respectively in 10-year-old children).

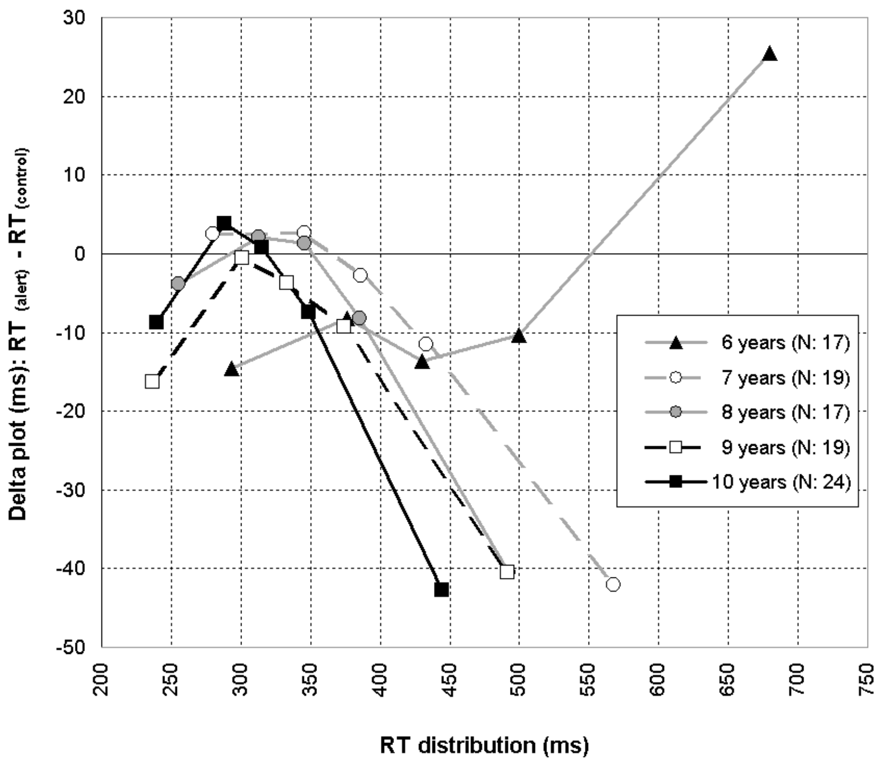

Figure 3: Delta plot RT as function of quintiles-RT (Q1 / Q2 / Q3 / Q4 / Q5) in the five age-groups (6 years / 7 years / 8 years / 9 years / 10 years).

24 ANOVAs run on each slope segment with age-group as between-subject factor confirmed that the alert effect diverged at the end of the RT distribution between 6 years and older children (see Annex 4). The effect size of age-group was larger in the Q4/5 than in the Q3/4 segment ([$F(4, 91) = 5.6$, $p = 0.00044$, $\eta_p^2 = 0.20$] and [$F(4, 91) = 2.0$, $p = 0.098$, $\eta_p^2 = 0.082$], respectively). In the Q4/5 segment, the slope was significantly different between 6-year-old children (+15±46%) and all other older children (p = 0.0083 between 6 and 7 years, p = 0.0013 between 6 years and all other age-groups). Slopes were negative in 7- to 10-year-old children (-20±33, -30±42, -31±36 and -42±40%, respectively) (slope differences from 7- to 10-year-old children were not statistically significant). In the Q3/4 segment, the slope was significantly higher in 6-year-old children (+2±34%) than in 8- and 10-year-old children (-22±34 and -24±23%, p = 0.032 and p = 0.021, respectively) and tended to be higher in 6-year-old children than in 7- and 9-year-old children (-16±33 and -14±28%, p = 0.089 and p = 0.12, respectively). In other segments, age-group was not statistically significant ([$F(4, 91) = 1.6$, $p = 0.27$, $\eta_p^2 = 0.054$] and [$F(4, 91) = 0.1$, $p = 0.99$, $\eta_p^2 = 0.003$], respectively in Q1/2 and Q2/3).

Discussion of distributional analysis

25 Distributional analysis suggested that the capacity to adequately use a warning signal appeared around the age of 7 years. The pattern, predicted by the theoretical model, characterized by an absent or moderate alert effect in the first part of the RT distribution, with a regular increase of the alert effect in the second part of the distribution, was found in 7- to 10-year-old children, while 6-year-old children showed an opposite pattern. Alert accelerated response times in the entire RT distribution except at the extreme end during which alert slowed-down responses. The pattern obtained in the first part of the RT

distribution may be interpreted as reflecting the impact of many erroneous or impulsive responses made by 6-year-old children in reaction to the warning signal. More precisely, some motor responses appear to be activated by the alert, but occurred during the time window of the target presentation causing an apparent alert effect. The slowing-down impact of alert on responses observed at the extreme end of the response distribution suggested that the warning signal could disrupt detection of a target in 6-year-old children. Distributional results therefore suggest (1) that 6-year-old children had difficulties correctly using the warning signal, and (2) that this capacity emerged around the age of 7 years. Alertness seems to continue to mature after the age of 7 years. Between the age of 7 and 10 years, the time before which alertness started to operate continues to decline with age (386 ms at 7 years, 346 ms at 8 years, 333 ms at 9 years and 315 ms at 10 years). Other parameters, such as the alert effect slope as a function of response time and the maximum magnitude of alert effect (occurring at the extreme end of the RT distribution), were very similar in 7- to 10-year-old children.

26 The hypothesis that the apparent alert effect observed in 6-year-old children during most of the RT distribution reflected false responses to the alert signal appears to be confirmed by the response pattern observed in older children. Eight-, 9- and 10-year-old children exhibited a similar apparent alert effect to that observed at 6 years, but which was clearly confined to the extreme start of the RT distribution. Although false responses did not completely disappear in children over the age of 6, distributional analysis clearly showed that they were dramatically decreased. This finding suggests that the capacities to inhibit false responses improve during the same age period as alertness capacities start to become efficient.

27 Delta plot results must be interpreted in the light of the following methodological limitation. The delta plot was calculated on the basis of 29 trials per quintile. This number of trials per quintile may be considered to be insufficient compared to the 72 trials used in the study by Ridderinkhof et al. (2005). The present experiment was designed to evaluate phasic attention, not the capacity to maintain attention over time. This constraint required the use of a short duration task (less than 7 minutes in this study) and, consequently, a task with a limited number of trials was designed. Moreover, only 14 trials were sufficient in a recent study concerning the maturation of inhibition engaged in a stroop task also using delta plot analysis (Bub et al., 2006).

CONCLUSION

28 Analysis of RT distribution and SOA effects demonstrated the existence of a developmental trajectory of alertness during the 6 to 10 years period. Results obtained by both analyses converged on two points: (1) 6-year-old children had difficulties correctly using the alert signal, and (2) alertness capacities emerged around the age of 7-8 years associated with a decrease of the delay beyond which the alert signal became efficient with increasing age. A consistent effect of the alert was detected at 7 years when assessed by the mean of the distributional analysis, and at 8 years when assessed by analysis of the impact of SOA duration on mean RT. Examination of the sensitivity of these two analyses indicated that the effect size of the Age-Alert-SOA interaction ($\eta_p^2 = 0.082$, $W = 0.82$) was lower than the effect size of Age on the delta-plot slope of the RT distribution ($\eta_p^2 = 0.12$, $W = 0.99$) and the effect size of Age on the last slope segment ($\eta_p^2 = 0.20$, $W = 0.97$)

corresponding to the maximum alert effect. This finding suggests that the capacity to use an alert signal emerged at the age of 7 years.

29 In the present study, the effect of age on the alertness task was studied by allocating children into class groups ordered by age (5 groups each covering one year; for details, see Table 1). Allocating children by age-group is the main method used in developmental studies. Except for the study by Drechsler et al. (2005), in which a longitudinal design was used, all other developmental studies mentioned above used age-group allocation to constitute the groups of children (Bedard et al., 2002; Davis et al., 2004; Luna et al., 2004; Ridderinkhof et al., 1997; Rueda et al., 2004; Williams et al., 1999). This method can result in the allocation of children of very similar age to two different age-groups, resulting in groups with a very small difference in terms of mean age. Statistical analysis showed that the mean age was very different between successive groups in this study with mean age increasing by approximately one year for each group. The sample size for each group was satisfactory compared with other developmental studies[1]. However, the sample size would be too small to demonstrate a potential significant difference between older groups for mean RT and variability of RT (The statistical power for these parameters was low between 8-9-year-old and 9-10-year-old children). In contrast, multiple statistical comparisons to assess the effect of alert according to SOA and age-group increased the likelihood of type I errors. However, statistical results concordantly demonstrated a significantly differentimpact of alert between 6- or 7-year-old children and older children for mean RT, variability of RT and delta-plot slope. The convergence of statistical results obtained with different parameters constitutes a strong argument to suggest that the capacities of children to use an alert changed at about the age of 7-8 years in the sample of children of this study. The age range of children was restricted from 6 to 10 years, which did not allow analysis of whetherphasic alertness continues to develop during adolescence or reaches an asymptotic level of efficiency.

30 Participants performing a simple detection task made many erroneous or impulsive responses to the alert. An unknown number of false responses may therefore be confounding with expected responses (responses in reaction to presentation of the target) when only mean RT is analyzed. Slower participants presented a higher frequency of false responses to the alert during the time window of presentation of the target and, then, presented a higher risk of being confounded with correct responses to targets. Consequently, an apparent alert effect was frequently observed in young children (younger children present slower responses), which could explain why an alert effect was found for 5- and 6-year-old children in previous studies (Ridderinkhof et al., 1997; Rueda et al., 2004). Distributional analysis supports this hypothesis: 6-year-old children presented an apparent alert effect over the entire RT distribution except in the extreme end where the alert slowed response times. This alert effect pattern is clearly distinct from those observed in older children, as shown by the concave-downward function of the alert effect as a function of RT distribution, allowing false responses to the alert to be clearly distinguished from true responses to the target. These two kinds of responses are concentrated in the first part and in the second part of the RT distribution, respectively.

31 Previous studies have failed to demonstrate a clear developmental trajectory of phasic attention. Note that SOA was not manipulated or not analyzed in the studies conducted by Rueda et al. (2004) and Ridderinkhof et al. (1997) with participants aged from 6 years to adulthood and from 5 to 21 years, respectively. It is important to recall that the developmental trajectory of phasic attention (correct use of the alert signal was

evidenced around 7-8 years, not at 6 years) reported in the present experiment was only observed when the SOA duration was included as a within-subject factor and was confirmed by the distributional analysis. As reported by Rueda et al. (2004), Ridderinkhof et al. (1997) and Drechsler et al. (2005), a principal alert effect independent of age-group was found in the present study[2]. This finding highlights the importance of taking the temporal dimension into account to study maturation of attentional functions and more generally to study cognitive functions. The distributional approach would allow assessment of the temporal dimensions of phasic attention in developmental disorders, as in the Attention Deficit Hyperactivity Disorder (ADHD). Several authors have argued that the most consistent manifestations of ADHD is the high prevalence of 'moment-to-moment variability and inconsistency in performance, reflected by abnormal slowness and intra-individual RT variability (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Russell, Oades, Tannock et al., 2006). Previous studies have suggested that distributional analysis of RT is a powerful tool to reveal deficits in children with ADHD (Querne & Berquin, 2008) and to explore cognitive impairment (Castellanos et al., 2006) or the effect of pharmacological treatments (Ridderinkhof et al., 2005). To date, all studies using overall parameter analysis have failed to found impairment of phasic attention in children with ADHD although impairment of several components of attention (tonic, divided, focused) and inhibition has been demonstrated (Drechsler et al., 2005; Tucha, Prell, Mecklinger et al., 2006; Tucha, Walitza, Mecklinger et al., 2006). Future studies should re-examine the development of phasic attention in ADHD by analyzing processes of alert phasic attention byin taking the temporal dimension into account. The present study suggests that typically developing children committed many erroneous or impulsive responses in reaction to the warning signal as show by the first part of the delta-slope curve for alert. Previous studies have suggested that children with ADHD, especially those who are primarily hyperactive/impulsive, committed significantly more impulsive responses than typically developing children as revealed by distributional analysis of RT (Querne & Berquin, 2008). However, others studies in ADHD failed to demonstrate differences between children with ADHD (regardless of thesubtype) and typically developing children for RT in alert task (Tucha, Walitza, Mecklinger et al., 2006). This result could be due to the low sensitivity of the overall RT parameter analysis used to detect impulsive responses in children with or without developmental disorder. This suspected low sensitivity of overall RT analysis for the alert task could also be responsible for the absence ofeffect of methylphenidate observedduring the alert task in children with ADHD (Drechsler et al., 2005; Tucha, Prell, Mecklinger et al., 2006). As shown by Ridderinkhof et al. (2005), delta-plot analysis provides a very sensitive tool to study how methylphenidate modifies the timing of inhibition processes in children with ADHD (see also: Castellanos, Sonuga-Barke, Scheres et al., 2005). The alertness task designed in the present study may also be useful to study how pharmacological treatments impact on alert tasks in children with ADHD.

BIBLIOGRAPHY

Abraham, T., & Russsel, D. (2008). Statistical power analysis in psychological research. *Social and Personality Psychology Compass, 2/1*: 283-301.

Bedard, A. C., Nichols, S., Barbosa, J. A., Schachar, R., Logan, G. D., & Tannock, R. (2002). The development of selective inhibitory control across the life span. *Developmental Neuropsychology, 21 (1),* 93-111.

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: a dimensional and developmental study. *Developmental Neuropsychology, 26(2),* 571-593.

Brodeur, D. A., & Pond, M. (2001). The Development of Selective Attention in Children With Attention Deficit Hyperactivity Disorder. *Journal of Abnormal Child Psychology, 29(3),* 229–239.

Bub, D. N., Masson, M. E. J., & Lalonde, C. E. (2006). Cognitive Control in Children. Stroop Interference and Suppression of Word Reading. *Psychological Science, 17(4),* 351-357.

Castellanos, F. X., Sonuga-Barke, E. J., Milham, M. P., & Tannock, R. (2006). Characterizing cognition in ADHD: beyond executive dysfunction. *Trends in Cognitive Sciences, 10(3),* 117-123.

Castellanos, F. X., Sonuga-Barke, E. J., Scheres, A., Di Martino, A., Hyde, C., & Walters, J. R. (2005). Varieties of attention-deficit/hyperactivity disorder-related intra-individual variability. *Biological Psychiatry, 57(11),* 1416-1423

Davis, P. L., Segalowitz, S. J., & Gavin, W. J. (2004). Development of Response-Monitoring ERPs in 7- to 25-Year-Olds. *Developmental Neuropsychology, 25(3),* 355-376.

Drechsler, R., Brandeis, D., Foldenyi, M., Imhof, K., & Steinhausen, H. C. (2005). The course of neuropsychological functions in children with attention deficit hyperactivity disorder from late childhood to early adolescence. *Journal of Child Psychology Psychiatry, 46(8),* 824-836.

Fernandez-Duque, D., & Posner, M. I. (1997). Relating the mechanisms of orienting and alerting. *Neuropsychologia, 35(4),* 477-486.

Kaufman, A. S., Kaufman, J. C., Balgopal, R., & McLean, J. E. (1996). Comparison of Three WISC-III Short Forms: Weighing Psychometric, Clinical, and Practical Factors. *Journal of Clinical Child Psychology, 25(1),* 97-105.

Luna, B., Garver, K. E., Urban, T. A., Lazar, N. A., & Sweeney, J. A. (2004). Maturation of cognitive processes from late childhood to adulthood. *Child Development, 75(5),* 1357-1372.

Nebes, R. D., & Brady, C. B. (1993). Phasic and tonic alertness in Alzheimer's disease. *Cortex, 29(1),* 77-90.

Pietrzak, R. H., Mollica, C. M., Maruff, P., & Snyder, P. J. (2006). Cognitive effects of immediate-release methylphenidate in children with attention-deficit/hyperactivity disorder. *Neuroscience and Biobehavioral Reviews, 30(8),* 1225-1245.

Querne, L., & Berquin, P. (2008). Distinct response time distributions in Attention Deficit Hyperactivity Disorder subtypes. *Journal of Attention Disorders, August 25* [Epub ahead of print].

Ridderinkhof, K. R., Scheres, A., Oosterlaan, J., & Sergeant, J. A. (2005). Delta plots in the study of individual differences: new tools reveal response inhibition deficits in AD/HD that are eliminated by methylphenidate treatment. *Journal of Abnormal Psychology, 114(2),* 197-215.

Ridderinkhof, K. R., van der Molen, M. W., Band, G. P., & Bashore, T. R. (1997). Sources of interference from irrelevant information: a developmental study. *Journal of Experimental Child Psychology, 65(3),* 315-341.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42(8),* 1029-1040.

Russell, V. A., Oades, R. D, Tannock, R., Killeen, P. R., Auerbach, J. G., Johansen, E. B., et al. (2006). Response variability in Attention-Deficit/Hyperactivity Disorder: a neuronal and glial energetics hypothesis*. Behavioral and Brain Functions, 2:30.*

Tucha, O., Prell, S., Mecklinger, L., Bormann-Kischkel, C., Kübber, S., Linder, M., Walitza, S., & Lange K. W. (2006). Effects of methylphenidate on multiple components of attention in children with attention deficit hyperactivity disorder. *Psychopharmacology, 185(3),* 315-326.

Tucha, O., Walitza, S., Mecklinger, L., Sontag, T. A., Kübber, S., Linder, M., 1 Lange K. W. (2006). Attentional functioning in children with ADHD - predominantly hyperactive-impulsive type and children with ADHD - combined type. *Journal of Neural Transmission. 113(12*), 1943-1953.

Williams, B. R., Ponesse, J. S., Schachar, R. J., Logan, G. D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental Psychology, 35(1),* 205-213.

APPENDIXES

	SOA-100				SOA-450				SOA-450			
	Control		Alert		Control		Alert		Control		Alert	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
6-years	526	(104)	499	(106)	432	(71)	447	(84)	416	(66)	417	(64)
7-years	457	(81)	424	(76)	387	(75)	398	(79)	381	(79)	371	(73)
8-years	416	(85)	396	(87)	345	(74)	342	(71)	330	(70)	320	(70)
9-years	402	(101)	371	(77)	335	(79)	340	(79)	328	(62)	311	(66)
10-years	370	(64)	359	(72)	326	(57)	310	(51)	304	(48)	296	(48)

Annex 1: Mean RT (ms) and inter-individual S.D. (ms) per age-group (6 years / 7 years / 8 years / 9 years / 10 years) as a function of SOA (SOA-100 ms / SOA-450 ms / SOA-800 ms) and alert conditions (Control / Alert).

	SOA-100				SOA-450				SOA-450			
	Control		Alert		Control		Alert		Control		Alert	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
6-years	180	(58)	197	(94)	153	(54)	177	(67)	129	(48)	140	(66)
7-years	146	(50)	131	(34)	119	(52)	98	(37)	118	(53)	89	(33)
8-years	133	(44)	111	(42)	94	(46)	86	(37)	95	(45)	71	(24)
9-years	134	(71)	115	(59)	102	(51)	94	(50)	96	(46)	83	(41)
10-years	109	(43)	94	(44)	89	(50)	69	(33)	78	(35)	71	(44)

Annex 2: Variability for RT (intra-individual S.D. of RT in ms) and inter-individual S.D. (ms) per age-group (6 years / 7 years / 8 years / 9 years / 10 years) as a function of SOA (SOA-100 ms / SOA-450 ms / SOA-800 ms) and alert conditions (Control / Alert).

	SOA-100				SOA-450				SOA-450			
	Control		Alert		Control		Alert		Control		Alert	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
6-years	1.47	(2.53)	2.45	(4.90)	1.47	(2.53)	0.74	(1.64)	0.49	(1.38)	0.49	(1.38)
7-years	0.22	(0.96)	0.22	(0.96)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
8-years	0.00	(0.00)	0.25	(1.01)	0.00	(0.00)	0.00	(0.00)	0.49	(1.38)	0.00	(0.00)
9-years	0.00	(0.00)	0.22	(0.96)	0.00	(0.00)	0.00	(0.00)	0.22	(0.96)	0.00	(0.00)
10-years	0.00	(0.00)	0.00	(0.00)	0.17	(0.85)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)

Annex 3: Omissions (%) and inter-individual S.D. (in %) per age-group (6 years / 7 years / 8 years / 9 years / 10 years) as a function of SOA (SOA-100 ms / SOA-450 ms / SOA-800 ms) and alert conditions (Control / Alert).

	Delta plot for alert per quintile									
	Quintile 1		Quintile 2		Quintile 3		Quintile 4		Quintile 5	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
6-years	-15	(38)	-8	(22)	-14	(26)	-10	(37)	25	(101)
7-years	2	(30)	3	(14)	-3	(17)	-12	(26)	-42	(71)
8-years	-4	(17)	2	(15)	1	(17)	-8	(19)	-40	(55)
9-years	-16	(28)	-1	(15)	-4	(25)	-9	(25)	-41	(54)
10-years	-9	(25)	4	(13)	1	(15)	-7	(18)	-43	(49)

	Delta plot slope for alert per segment							
	Quintile[1-2] segment		Quintile[2-3] segment		Quintile[3/4] segment		Quintile[4-5] segment	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
6-years	4	(35)	-9	(30)	2	(34)	15	(46)
7-years	0	(40)	-9	(42)	-16	(33)	-20	(33)
8-years	16	(33)	-11	(30)	-22	(34)	-30	(42)
9-years	22	(37)	-7	(41)	-14	(28)	-31	(36)
10-years	26	(46)	-13	(36)	-24	(23)	-43	(40)

Annex 4: Delta plot for (ms) per quintiles (Q1 / Q2 / Q3 / Q4 / Q5) [upper panel] and Delta plot slopes (in %) per segments of the RT distribution (Q1/2 / Q2/3 / Q3/4 / Q4/5) per age-group (6 years / 7 years / 8 years / 9 years / 10 years) [lower panel].

NOTES

1. In developmental studies consecrated to the phasic alert, allocation of children in groups was as following: 5-7, 8-9 and 10-12 years with 11 to 18 children per group (Ridderinkhof et al., 1997); 6, 7, 8, 9, 10 years and adults with 12 children per group (Rueda et al., 2004); 24 children aged 8 to 13 years which realized the alert task 3 times at an age mean of 10.8, 12.0 and 13.3 years, respectively (Drechsler et al., 2005). Allocation of children ingroups in other developmental studies mentioned in the present study was as following: 6-8, 9-12, 13-17 years and adults with 40 to 62 children per group (Bedard et al., 2002); from 7 to 18 years (each group covering on year and adults with 8 to 18 children per group (Davies et al., 2004); 6-8, 9-12, 13-17 years and adults with 29 to 41 children per group (Williams et al., 1999).

2. The principal Alert effect on mean RT was significant [$F(1,91)=17.9$, $p<0.0001$, $\eta_p^2 = 0.17$] while the Age-Alert interaction failed to approached statistical significance [$F(4,91)=0.5$, $p=0.74$, $\eta_p^2 = 0.021$] in the present study.

ABSTRACTS

This paper focuses on the maturation of the temporal aspect of phasic attention. 96 children (age range from 6 to 10 years) performed a detection task either alone or preceded by a visual alert signal. The Stimulus Onset Asynchrony (SOA) between the alert and the visual target was manipulated (100, 450 and 800 ms). Analysis of the mean RT (taking into account the SOA) and the response distribution (delta plot) converged on two points: (1) 6-year-old children experienced difficulties using the alert signal, and (2) alertness capacities emerged around the age of 7-8 years associated with a decrease of the delay beyond which the alert signal became efficient with increasing age. Distributional analysis distinguished erroneous or impulsive responses in reaction to the alert signal from those for which the alert was used correctly to prepare detection of the target.

Le développement des aspects temporels de l'attention phasique a été étudié dans ce travail. 96 enfants (âgés de 6 à 10 ans) ont réalisé une tâche de détection simple précédée ou non par une alerte. L'intervalle de temps entre alertes et cibles visuelles était manipulé ("Stimulus Onset Asynchrony": SOA de 100, 450 et 800 ms). L'analyse des temps de réponse (prenant en compte le SOA) et leur distribution (delta plot) convergent sur deux points : (1) à 6 ans, les enfants ne semblent pas capables d'utiliser efficacement l'alerte, et (2) les capacités d'alerte deviendraient efficientes à partir de 7-8 ans, pouvant être mobilisées de plus en plus rapidement à mesure que l'age des enfants augmente. L'analyse distributionnelle permet de distinguer les réponses erronées ou impulsives qui sont données en réponse à l'alerte de celles pour lesquelles l'alerte a été utilisée de façon correcte pour préparer la détection de la cible.

INDEX

Keywords: alertness, delta plot, development, distribution analysis, phasic attention

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