Development of attentional networks in intellectually gifted children

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Abstract

Intellectually gifted children have high performance in many domains of the attention than intellectually average children. However, few studies investigated the development of the alerting, orienting and executive control networks, in intellectually gifted children. The aim of our study is investigated the development of three attentional networks in intellectually gifted children.

Fifty-four intellectually gifted children (age range 8–14 years-old) were compared to 54 intellectually average children (age range 8–14 years-old) and 60 young adults (age range 19–25 years-old) using the Attention Network Test to assess these three attentional constructs. Results indicated intellectually gifted children had better performance than intellectually average children in executive control only. Both children groups have lower attentional network scores than young adults. Intellectually gifted children have probably the same development of the intellectually gifted children in all attentional networks to the late childhood at adolescence. But they have better ability to focus volitionally in order to solve a simple conflict than intellectually average children.

Keywords

Intellectual giftedness; Attention Networks Test; Executive control; Attentional development; Developmental trajectory

Intellectually gifted children (IGC) outperform in the most of the attentional tasks (Johnson, Im-Bolter, & Pascual-Leone, 2003; Shi, Tao, Chen, Cheng, Wang, & Zhang, 2013). Their attentional abilities seem to be more efficient than those of the intellectually average children (IAC). However, the development of their attentional abilities has been poorly investigated in the literature. Attention has a crucial role in the child's general cognitive development (Pascual-Leone, 1987; Johnson et al., 2003; see de Ribaupierre & Lecerf, 2017 for a discussion).

Some studies assume IGC have a particular cognitive development (Morelock & Morrison, 1999; Steiner, & Carr, 2003; Vaivre-Douret, 2011). Their cognitive abilities would develop at a faster rate than expected for their chronological age (Morelock & Morrison, 1999). In the early stages of development, these children show more advanced performance than age-matched peers in cognitive domains such as language and memory (Kerr & Multon, 2015; Porath, 2006; Vaivre-Douret, 2011). Some authors claim children with high intelligence have a way of thinking more characteristic of older counterpart (Solé-Casals et al., 2019). In other words, the rate of development of some cognitive aptitudes in intellectual giftedness differ from those in counterparts. This particular cognitive development is linked with an atypical development of the brain in adolescence (Ma et al., 2017; Mrazik & Dombrowski, 2010; Solé-Casals et al., 2019). Such studies show intellectual giftedness adolescents have higher efficient connections between different brain structural networks than intellectually average adolescents. Intellectual giftedness also confers an advantage in the integration of diverse information from brain areas accurately and quickly (Ma et al., 2017; Solé-Casals et al., 2019). IGC have better efficiency of global information processing than age-matched peers. It would be due to a particular pattern of brain networks and an extensive communication between some brain areas (Ma et al., 2017; Solé-Casals et al.,

2019). This specific pattern of networks might explain their more accurate and faster high-order cognitive processing than those of their age-matched peers (Solé-Casals et al., 2019).

In simple elementary cognitive tasks (e.g. inspection time or choice reaction time tasks), IGC have faster response times than IAC (Duan, Dan, & Shi, 2013; Kranzler, Whang, & Jensen, 1994). This discrepancy of speed responses may reflect a high degree of automatization processing in IGC (Gaultney, Bjorklund, & Goldstein, 1996). However, their high speed of processing seems to be relative. The faster speed processing in IGC can be moderated by the demand of the task. According to the demands of the cognitive task, this difference between both gifted and nongifted group might disappear (Geary & Brown, 1991; Lajoie & Shore, 1986). In conclusion, high intelligence does not always reflect faster performance (Reams, Chamrad & Robinson, 1990). In the same vein, some studies have shown an equivalent learning progression in intellectually gifted and average children (Vogelaar, Bakker, Elliott, & Resing, 2017a; 2017b; Vogelaar, Resing, Stad, & Sweijen, 2019). Although there are some contradictory results (Calero, Belen, & Robles, 2011; Kanevsky & Geake, 2004), the rapidity to learn in IGC seems not to distinguish from IAC in the potential of learning. The specificity of intellectual giftedness concerns on the high capacity to learn and to generalize their newly acquired knowledge in other contexts (Calero et al., 2011; Vogelaar et al., 2017a, 2017b, 2019). This high learning capacity might be tied to their high performance in reasoning (Caropreso & White, 1994), working memory (Calero, García-Martín, Jiménez, Kazén, & Araque, 2007; Hoard, Geary, Byrd-Craven, & Nugent, 2008; Leikin, Paz-Baruch, & Leikin, 2013; van Viersen, Kroesbergen, Slot, & de Bree, 2014), metacognitive abilities (Oppong, Shore, Muis, 2019) and executive functions (Arffa, 2007).

The reasoning, working memory, metacognitive abilities and executive functions have some inter-related processes such as cognitive control processes (Efklides, 2008; Engle, 2018; Fernandez-Duque, Baird, & Posner, 2000). These processes are an important milestone of the attention which is strongly related to the intelligence (Burns, Nettelbeck, & McPherson, 2009; Cowan, Fristoe, Elliott, Brunner, & Saults, 2006; Schweizer & Moosbrugger, 2004; Schweizer et al., 2005; Tillman et al., 2009; Tourva, Spanoudis, & Demetriou, 2015). IGC have higher performance than IAC in attentional tasks involving the cognitive control processes (Duan, Shi, Wu, Mou, Cui, Wang, 2009; Johnson et al., 2003; Liu, Xiao, Shi, Zhao, 2011a; 2011b). Furthermore, attention is a basic cognitive function essential for the deployment of high-order cognitive processes. Attention is crucial to select actively aspects of our environment and to regulate voluntarily our cognitions and emotions (Posner, Rothbart, Sheese, Voelker, 2014). Attention allows to regulate various neural networks through attentional networks involved in the alert state, orienting or executive control (Posner & Rothbart, 2007).

The framework proposed by Posner and Petersen identifies three attentional networks which are functionally and anatomically distinct: alerting, orienting and executive control (Posner & Petersen, 1990; see Petersen & Posner, 2012 for a recent review). Alerting allows to supply and maintain an optimal state of vigilance during a task (Petersen & Posner, 2012). Alerting network is based on right frontal and parietal regions (Raz, 2004). Orienting is the ability to prioritize the processing of any stimulus from selecting a salient information in a sensory input (Petersen & Posner, 2012; Posner, 1980). Orienting network involves mainly an activity of parietal areas and frontal eye field (Raz, 2004). Executive control is the ability to focus volitionally in order to solve a simple conflict (Posner & DiGirolamo, 1998). Executive

control network is related to the activation of anterior cingulate cortex and prefrontal areas (Raz, 2004).

Some studies have investigated the relation of each attentional network with the intellectual abilities. The alerting effect seems not to be related to the IQ (Konrad et al., 2005). However, sustained attention, that is one facet of the alerting network, is involved in the intellectual performance (Schweizer, Zimmermann, & Koch, 2000; Schweizer, & Moosbrugger, 2004). The IGC have better attentional resources and are less inattentive than their pairs for the visual processing (Shi et al., 2013; Zhang et al., 2016). In the same vein, the orienting effect seems not to be linked to the IQ (Konrad et al., 2005). Nevertheless, some studies have shown a relation between the selective attention, that is the endogenous aspect of the orienting network, and the intellectual abilities (Schweizer et al., 2005; Schweizer & Moosbrugger, 2004). Furthermore, the executive control has an important role in the intellectual functioning (Cowan et al., 2006; Engle, 2018; Engle, Tuholski, Laughlin, & Conway, 1999). Some studies have shown the executive control effect is significantly correlated with the intellectual abilities and the age (Konrad et al., 2005; Tourva, et al., 2015).

In the literature, most of studies have highlighted each attentional network develops at different ages (Lewis, Reeve & Johnson, 2018; Pozuelos, Paz-Alonso, Castillo, Fuentes, & Rueda, 2014; Rueda, Posner, Rothbart, & Davis-Stober, 2004; Mullane, Lawrence, Corkum, Klein, & McLaughlin, 2016). The alerting network continually develops from 6 and 12 years-old (Lewis et al., 2016; Mullane et al., 2016, Pozuelos et al., 2014; Rueda et al., 2004). Concerning its development into young adults, the literature is less consistent. Some authors have shown the efficiency of the alerting network get better until the early adulthood (Rueda et al., 2004), whereas other authors did not find a significant difference between children and young adults (Konrad et al., 2005). The efficiency of the orienting network increases from

early childhood to 7 years-old (Mezzacappa, 2004). Most of the studies have shown stability in the performance of the orienting network (Lewis et al., 2016; Mullane et al., 2016; Rueda et al., 2004). However, other studies have found the efficiency of the orienting network improves beyond the childhood (Konrad et al., 2005; Pozuelos et al., 2014). So, the growth of the orienting network would be well developed by the age of 7 years-old, and the orienting effect would improve slowly across the older children (Pozuelos et al., 2014). Finally, the executive control system develops mainly during the early childhood (Rueda, Posner, & Rothbart, 2005). The development of executive control network continues and extends beyond childhood to adulthood (Kray, Eber, & Linderberge, 2004; Davidson, Amso, Cruess, & Diamond, 2006; Diamond, 2013; Konrad et al., 2005; Rueda et al., 2004). All of these studies have shown each attentional network has a distinctive developmental trajectory and specific critical periods in its development.

A lot of studies have investigated the growth of these attentional networks in the children having atypically development such as children having an attentional deficit with or without hyperactivity disorder (ADHD; e.g., Adolfsdottir, Sorensen, & Lundervold, 2008; Kratz, Studer, Malcherek, Erbe, Moll, & Heinrich, 2011; Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2011), or bilingual children (e.g., Antón et al., 2014; Yang & Yang, 2016), or children with chromosome 22q11.2 deletion syndrome (e.g., Stoddard, Beckett, & Simon, 2010), or in the children with an high-functioning (e.g., Greene, Colich, Iacoboni, Zaidel, Bookheimer, & Dapretto, 2011). The IGC have some particularity in their cognitive development (Kerr & Multon, 2015; Porath, 2006; Vaivre-Douret, 2011). However, as far we know, no study has investigated the development of the attentional networks in children having a high intellectual potential. Therefore, the aim of this current study is to investigate the development of each attentional network i.e., alerting, orienting and executive

control, in IGC identified with standardized intellectual test (i.e., 2 standard deviations above the average, see Cao, Jung, & Lee, 2017 for review). For this purpose, we performed an investigation of each attentional network from IGC in two steps: (1) we compared the performance in each attentional network of IGC and those of IAC, itself compared with those of young adults; (2) then, we explored the cross-sectional developmental trajectories of each attentional network in IGC, and compared with those of their age-matched peers.

Based on the literature on typical development of attentional networks and its relationship with intelligence, we hypothesized that: (1) IGC will have better performance than IAC in only executive control; (2) IGC will have lower performance than young adults in alerting and executive control; (3) IAC will show worse performance than young adults in alerting and executive control. Knowing that the current study of the developmental trajectories of attentional networks in IGC is exploratory, we have not put forward any specific hypothesis about their rate of development.

Methods

Participants

A sample of 54 IGC (mean age: 11.86 years, SD: 1.25, 22 females), 54 IAC (mean age: 11.84 years, SD: 1.25, 22 females) and 60 undergraduate students (mean age: 20.87 years, SD: 1.57, 50 females) participated in our study. In young adults group, all participants were undergraduate students from the University of Picardie. They were recruited on a voluntary basis. All typical children were recruited in elementary and middle schools. IGC were recruited with the help of licensed psychologists or enrolled in special gifted programs in middle school. No children had known learning disorders; all adults and children had normal or corrected vision, and all were native French speakers. The information about our

whole sample is summarized in Table 1. Children groups did not significantly differ in terms of age, $t(106.00) = 0.101$, $p = .920$, $d = 0.019$.

The inclusion criterion for children in the intellectually gifted group was identified by the 95th percentile on one of two IQ tests such as Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2005) and Raven's Standard Progressive Matrices (RSPM; Raven, Raven, & Court, 2000). Forty-five IGC is identified by WISC-IV and 9 gifted children by RSPM. In the intellectually average group, all children had an IQ between 85 and 115, estimated with RSPM only.

Table 1: Description of the whole sample

Group	n	Gender (% Female)	Age (in years)			IQ		
			M (SD)	Skew	Kurtosis	M (SD)	Skew	Kurtosis
IAC	54	40.74	11.84 (1.25)	-0.33	-0.03	103.44 (6.93)	0.09	-1.24
IGC	54	40.74	11.86 (1.25)	-0.19	-0.30	139.91 (8.09)	0.09	-0.53
Young adults	60	83.33	20.87 (1.57)	1.21	1.13	-	-	-

Notes. N = 168. IGC = Intellectually Gifted Children ; IAC = Intellectually Average Children.

Measure

The Attention Network Test - Child version (ANT; Rueda et al., 2004) was used to assess the performance in 3 independent attentional networks simultaneously: alerting, orienting and executive control. The ANT was computerized using PsychoPy (Peirce, 2007; 2008). All stimuli of the task were downloaded from the author website at this address: https://www.sacklerinstitute.org/cornell/assays_and_tools/ant/jin.fan/. The participant was instructed to indicate the direction of the central fish by pressing left or right button on the keyboard, the more rapidly possible without making an error. As presented by the Figure 1, each trial had the same structure: (1) a fixation cross was shown during a time randomly

100 ms: no asterisk was shown on the screen (no cue condition), an asterisk was appeared in the middle of the screen instead of the cross of fixation (central cue condition), an asterisk was displayed below and another above the cross of fixation (double cue condition) or the correct location of the target below or above the fixation cross was indicated at 100% by an asterisk (spatial valid cue condition); (3) after a stimulus-onset asynchrony (SOA) fixed at 400 ms, the target was displayed on the screen: either a single fish above or below the fixation cross (i.e., neutral condition), or the middle fish in the same direction of 4 others (i.e., congruent condition), or the middle fish in the opposite direction of 4 others (i.e., incongruent condition); (4) the target was presented until the participant's response or limit to 1700 ms. Then, the next trial started again at the step 1. The task began a training block with 24 trials, including feedback for 500 ms. Then, the participants had to perform 288 trials without feedback divided into 3 experimental blocks of 96 trials each, with 5 s break between each block.

For each participant, average accuracy and median response times (RTs) were recorded for each condition. RTs were considered only for correct trials; RTs faster than 200 ms or slower than 1700 ms were considered as extreme value and excluded from analyses (0.49% of trials). Following the recommendation of MacLeod et al. (2010), the present study will consider both ER and RT as performance measures. From dependent variables (i.e. RT or rate of errors) of each condition, we computed the effect of each attentional network based on the subtraction method (Fan, McCandliss, Sommer, Raz & Posner, 2002): (1) the alerting effect was computed by subtracting no cue condition to double cue condition. Indeed, the double cue alerts only the child to the imminent appearance of the target, without providing information about the target location; (2) the orienting effect was computed by subtracting central cue condition to spatial valid condition. Indeed, the central cue orients the attention to

the screen center, whereas the spatial cue provides successful information about the target location. Thus, the difference between these two conditions indicates the child's ability for orienting his or her attention toward a salient stimulus; (3) the executive control effect was computed by subtracting incongruent condition to congruent condition. Indeed, the incongruent condition requires the child to control his or her response in relation to the congruent condition. Higher are the scores (i.e. RT or rate of errors), less efficient is the attentional network.

Figure 1. Procedure for the Attention Network Test.

Procedure

All undergraduate students were all informed about the aim of the study, then signed informed consent. In both children group, all legal guardians were received and signed an informed consent which exposted the aim of this current study. Before testing took place, the objectives of the study were explained to the children, who then gave oral agreement for their participation. All participants performed the ANT task collectively within their group in around 20 minutes.

Data Analysis

The data and R scripts needed to replicate the statistical analyses are available on the Open Science Framework platform at <https://osf.io/936dz/>. All data analyses were realized with R 3.6.1 (R Core Team, 2019). Following the recommendations of MacLeod et al. (2010), both RT and PE were analyzed separately. Both dependent variables were considered as indicators of performance on the attentional networks in terms of speed and accurate (Wickelgren, 1977).

A first phase of analysis was performed to compare performance in different groups for each condition, then for each attention network. For this, two repeated-measures analysis of variance (RM-ANOVA) were performed. As recommended by Bakeman (2005), all effect sizes for mixed design were computed using generalized eta squared (η_G^2).

In the second phase of analysis, three developmental trajectories were performed for each child group (i.e., IGC and IAC) using linear regression models (Thomas, Annaz, Ansari, Scerif, Jarrold, & Karmiloff-Smith, 2009). The linear model of each attentional network was computed for each dependent variable (i.e., RT and PE). Then, a repeated-measures cross-sectional analysis of covariance (RM-ANCOVA) was performed to compare the three developmental trajectories within each child group of attention network score (in terms of

speed and errors) at the youngest age tested (intercept) and the rate of development (gradient; Thomas et al., 2009). Finally, the groups were compared using a RM-ANCOVA. This mixed design was used to examine whether the relationship between the development of each attention network was the same for IGC and IAC.

Post-hoc tests were performed using Tuckey's HSD with a Holm's correction of p-values for multiple comparisons (Holm, 1979). For all repeated-measures design, the sphericity assumption was assessed by Mauchly's test (Mauchly, 1940). When this test revealed a violation of the sphericity assumption, a subsequent Greenhouse-Geiser correction was applied at the results of analysis. For all statistical analyses, the violation of each statistical assumptions (i.e. normality and homoscedasticity) was checked by a graphical visualization. The influence of extreme values is assessed by Cook's D statistics (Cook, 1977). The cutoff of case identification is determined to use the F distribution with $df = (k + 1, n - k - 1)$ and $\alpha = .50$, where k is the number of predictors, and n is the number of observations (Cohen, Cohen, West, & Aiken, 2003). In all statistical analyses, no Cook's D statistics exceed the threshold computed by the formula from Cohen et al. (2003).

Results

Comparison between intellectually gifted children, intellectually average children, and young adults

General analysis

We first investigated the effect of the group on the average of median RTs and the average of PE separately in each experimental conditions. A 3 (Group) $\times$ 4 (Cues) $\times$ 3 (Flankers) RM-ANOVA was computed separately for RT and PE. The comparison between the IGC and IAC groups may provide the information regarding the effect of intellectual giftedness on the experimental conditions, while those between the young adult and IAC

groups may provide information about the typical development of performance on all experimental conditions. Table 2 shows the results in each experimental condition for each group.

Table 2

Mean of RT and PE for each experimental condition of Attention Networks Test (ANT) from IGC, IAC and young adults.

Group		Cue					Flanker	
		No	Center	Double	Valid	Neutral	Congruent	Incongruent
RT (ms)	IGC	663.06 (100.85)	647.12 (100.18)	635.75 (103.66)	600.94 (95.09)	593.19 (86.90)	616.62 (91.56)	700.33 (95.97)
	IAC	674.82 (105.90)	654.79 (96.73)	642.48 (98.76)	614.74 (91.74)	597.16 (82.80)	624.37 (81.42)	718.59 (93.78)
	Young Adult	569.34 (65.73)	552.88 (68.05)	548.31 (69.58)	525.79 (65.53)	509.09 (54.20)	537.16 (56.03)	600.99 (61.20)
PE (% errors)	IGC	2.55 (3.95)	3.05 (4.89)	2.54 (4.48)	2.20 (4.14)	2.21 (3.32)	0.87 (1.93)	4.67 (5.96)
	IAC	5.25 (6.56)	4.60 (6.43)	4.28 (6.04)	3.59 (5.58)	3.83 (4.97)	1.76 (3.44)	7.70 (7.76)
	Young Adult	1.41 (2.80)	1.09 (2.66)	1.18 (2.80)	0.69 (1.73)	0.83 (1.88)	0.35 (1.22)	2.10 (3.58)

Notes. IGC = Intellectually Gifted Children; IAC = Intellectually Average Children; RT = Responses Time; PE = Percentage of Errors; Standard Deviation are in parentheses.

Response time

A significant main effect of the group was found, $F(2, 165) = 33.64, p < .001, \eta_G^2 = .26$. The Tukey's HSD post-hoc analysis showed IGC, $M = 635.71, SD = 102.34$, and IAC, $M = 646.71, SD = 100.57$ have longer RTs than young adults, $M = 549.08, SD = 68.89$, but no significant difference with RT between IGC and IAC. A significant interaction between group and cue was found, $F(5.59, 461.26) = 3.67, p = .002, \eta_G^2 = .002$. The Tukey's HSD post-hoc analysis with a Holm's correction showed IGC and IAC have longer RTs from young adults, but no significant difference with RTs between IGC and IAC in all cue condition (see Table 2). A significant interaction between group and flanker has also found, $F(3.49, 288.29) =$

11.02, $p < .001$, $\eta_G^2 = .006$. The Tukey's HSD post-hoc analysis with a Holm's correction showed IGC and IAC have longer RTs than young adults, but no significant difference with RTs between IGC and IAC in all flanker condition (see Table 2). There was no Group $\times$ Cue $\times$ Flanker interaction, $F(10.76, 887.66) = 1.75$, $p = .060$, $\eta_G^2 = .001$.

Proportion of errors

An arcsin transformation has been applied on the dependent variable in order to manage the violation of normality assumption of residuals (see Unsworth, Redick, Heitz, Broadway, & Engle, 2009 for similar problem). A significant main effect of the group was found, $F(2, 165) = 33.99$, $p < .001$, $\eta_G^2 = .10$. The Tukey's HSD post-hoc analysis showed IGC, $M = 2.58$, $SD = 4.38$, and IAC, $M = 4.43$, $SD = 6.18$, made significantly more errors than young adults, $M = 1.10$, $SD = 2.54$, but IGC had lower PE than IAC. A significant interaction between group and flanker was found, $F(3.07, 253.62) = 6.09$, $p < .001$, $\eta_G^2 = .02$. The Tukey's HSD post-hoc analysis showed IGC and IAC had higher PE than young adults, but IGC did significantly less errors than IAC in neutral and incongruent conditions (see Table 2). Only IAC did more errors than young adult, but their PEs did not significantly differ these of IGC in congruent condition (see Table 2). There was no Group $\times$ Cue interaction, $F(5.82, 480.06) = 1.16$, $p = .327$, $\eta_G^2 = .02$, nor Group $\times$ Cue $\times$ Flanker interaction, $F(11.41, 941.42) = 1.04$, $p = .411$, $\eta_G^2 = .004$.

Attentional networks

A RM-ANOVA was performed separately for RT and PE with Group as between-subjects factor and Attentional Network as within-subjects factor. The results related to RT and PE indexes are illustrated for the three attentional networks in Figure 2.

Figure 2. Performance at each attentional network by group in: (A) response time and proportion of errors (B).

Response time

A significant main effect of the group was found, $F(2, 165) = 19.91, p < .001, \eta_G^2 = .08$. The Tukey's HSD post-hoc analysis showed IGC, $M = 52.40, SD = 39.16$, and IAC, $M = 55.54, SD = 42.63$, had higher Attentional Network indexes than young adults, $M = 37.31, SD = 27.42$, but both children groups did not significantly differ. A significant interaction between group and attentional networks was found, $F(4, 330) = 3.29, p = .012, \eta_G^2 = .02$. In alerting network, the Tukey's HSD post-hoc analysis with Holm's correction indicated that both children group did not differ from young adults (see Figure 2.A). In orienting network, the Tukey's HSD post-hoc analysis with Holm's correction showed only IGC had longer RTs than young adults, but were not different of RTs from IAC (see Figure 2.A). In executive control network, the Tukey's HSD post-hoc analysis with Holm's correction suggested IGC

and IAC had longer RTs than young adults, but both children groups did not significantly differ (see Figure 2.A).

Proportion of errors

A significant main effect of the group was found, $F(2, 165) = 14.15, p < .001, \eta_G^2 = .06$. The Tukey's HSD post-hoc analysis with Holm's correction showed IGC, $M = 1.56, SD = 3.78$, had lower Attentional Networks indexes than IAC, $M = 2.64, SD = 4.49$, but both children groups had higher Attentional Network indexes than young adults, $M = 0.80, SD = 2.18$. A significant interaction between group and attentional networks was found, $F(3.41, 281.35) = 6.10, p < .001, \eta_G^2 = .05$. In alerting and orienting network, the Tukey's HSD post-hoc analysis with Holm's correction indicated that IGC did not differ from IAC, nor from young adults (see Figure 2.B). In executive control network, the Tukey's HSD post-hoc analysis with Holm's correction suggested IGC had lower errors than IAC, but both children groups had higher PE than young adults (see Figure 2.B).

Developmental Trajectory of Each Attentional Networks in Intellectually Gifted and Average Children

Developmental trajectories of three attentional networks within each group (i.e., IAC and IGC) was compared separately for RT and PE using a RM-ANCOVA with Attentional Network as within-subjects and Chronological Age as covariate. Then, both groups were directly compared separately for RT and PE using a RM-ANCOVA with Group as between-subjects, Attentional Network as within-subjects and Chronological Age as covariate. The results related to developmental trajectories of RT and PE indexes are illustrated for the three attentional networks within each group in Figure 3 and Figure 4.

Figure 3. Developmental trajectories of each attentional network for response time in intellectually giftedness children (IGC) (A) and intellectually average children (IAC) (B).

Figure 4. Developmental trajectories of each attentional network for proportion of errors in intellectually giftedness children (IGC) (A) and intellectually average children (IAC) (B).

Response time

IAC had RT on alerting and orienting networks which did not improve reliably with chronological age, alerting: $R^2 = 0.003$, $F(1, 52) = 0.19$, $p = .666$; orienting: $R^2 = 0.04$, $F(1, 52) = 1.90$, $p = .174$, but performance on executive control network improved reliably with increasing the age, $R^2 = 0.08$, $F(1, 52) = 4.49$, $p = .039$. A comparison of the attentional networks indicated that onset of performance on the three attentional networks was dissimilar, $F(2, 104) = 73.07$, $p < .001$, $\eta_G^2 = .43$. In others words, RTs performed by the youngest children tested were different for each attentional networks (see Figure 3.A). A significant interaction between attentional networks and chronological was found, $F(2, 104) = 4.06$, $p = .020$, $\eta_G^2 = .04$. IAC had differently rate of development on the three attentional networks (see Figure 3.A). The relationship between alerting and orienting networks and chronological age was not reliable. So, the different rate of development on the three attentional networks should be interpreted with caution.

IGC had RTs on alerting network which improved reliably with increasing age, $R^2 = 0.10$, $F(1, 52) = 5.61$, $p = .022$, but their performance on orienting, $R^2 = 0.01$, $F(1, 52) = 0.32$, $p = .575$, and executive control networks, $R^2 = 0.02$, $F(1, 52) = 1.04$, $p = .313$, did not improve reliably with age. A comparison of the attentional networks indicated that onset of performance (RT were performed by the youngest children tested) on the three attentional networks was unlike, $F(1.77, 92.24) = 54.27$, $p < .001$, $\eta_G^2 = .37$, but no interaction of attentional networks by chronological age was found, $F(2, 104) = 1.09$, $p = .341$, $\eta_G^2 = .01$. In others words, the rate of development on the three attentional networks was similar (see Figure 3.B).

Both groups were directly compared in a mixed design analysis of variance to explore whether the developmental trajectories of each attentional networks were the same for

intellectually gifted and average children. The comparison showed that no interaction between groups and attentional networks, $F(1.97, 204.63) = 2.29, p = .104, \eta_G^2 = .01$. For both groups, alerting performance is faster than orienting which is faster than executive control. The difference between both groups in the rate of development on the three attentional networks did not significantly reliable, $F(1.97, 204.63) = 2.42, p = .091, \eta_G^2 = .01$.

Proportion of errors

For intellectual average group, the relationship between the PE and chronological age did not improve reliably on alerting, $R^2 = 0.028, F(1, 52) = 1.51, p = .224$, orienting, $R^2 = 0.007, F(1, 52) = 0.38, p = .539$, and executive control networks, $R^2 = 0.015, F(1, 52) = 0.80, p = .374$. A comparison of the attentional networks indicated that onset of performance on the three attentional networks was dissimilar, $F(1.74, 90.37) = 29.19, p < .001, \eta_G^2 = .27$. In others words, PE performed by the youngest children tested were different for each attentional networks (see Figure 4.A). No interaction between attentional networks and chronological was significantly found, $F(1.74, 90.37) = 1.25, p = .289, \eta_G^2 = .02$. The rate of development was similar in the three attentional networks (see Figure 4.A). Because of the relationship between the three attentional networks and chronological age was not reliable, the different rate of development on the three attentional networks should be interpreted with caution.

Similarly, for intellectually gifted group, the relationship between the proportion of errors and chronological age did not improve on alerting, $R^2 = 0.024, F(1, 52) = 1.28, p = .264$, orienting, $R^2 = 0.015, F(1, 52) = 0.82, p = .370$, and executive control networks, $R^2 < 0.01, F(1, 52) = 0.03, p = .870$. A comparison of the attentional networks indicated that onset of performance (PE were performed by the youngest children tested) on the three attentional networks was unlike, $F(1.64, 85.31) = 18.74, p < .001, \eta_G^2 = .19$, but no

interaction of attentional networks by chronological age was found, $F(1.64, 85.31) = 0.44$, $p = .606$, $\eta_G^2 < .01$. In others words, the rate of development on the three attentional networks developed similarly (see Figure 4.B). Because of the relationship between the three attentional networks and chronological age was not reliable, the different rate of development on the three attentional networks should be interpreted with caution.

Both groups were directly compared in a mixed design analyse of variance to explore whether the developmental trajectories of each attentional networks were the same for intellectually gifted and average children. The comparison showed that no interaction between groups and attentional networks, $F(1.97, 204.63) = 2.29$, $p = .104$, $\eta_G^2 = .01$. For both groups, alerting performance is faster than orienting which is faster than executive control. The difference between both groups in the rate of development on the three attentional networks did not significantly reliable, $F(1.97, 204.63) = 2.42$, $p = .091$, $\eta_G^2 = .01$.

Discussion

Most of studies have shown IGC outperform at some domains of the attention, such as sustained attention (Shi et al., 2013) and executive control (Duan et al., 2009; Liu et al., 2011a; 2011b). However, as far we know, no study has investigated the development of the attentional networks in children having a high intellectual potential. The results of this current study provide additional information on the characteristics of the attentional development in IGC.

Our findings showed the IGC did not differ from the IAC on the speed of the attentional monitoring, but they were more accurate than the IAC for the whole attentional task. In accordance with the literature, we found the attentional monitoring improves with age (Konrad et al., 2005; Rueda et al., 2004). On the alerting effect, our results highlighted IGC did not differ from the performance of IAC or young adults. Their state of vigilance would

not be disparate from those of their counterparts. In literature, IGC have better performance in sustained attention i.e., the intrinsic aspect of the alerting (Shi et al., 2014). However, our study has shown they did not take advantage of the external warning involving the phasic mechanism of the alerting. In addition, our findings confirmed the alerting effect enhances slowly through the late childhood (Mullane et al., 2016; Pozuelos et al., 2014; Rueda et al., 2004), even until the early adolescence (Lewis et al., 2016). Both children groups did not differ from the young adults on the alerting effect, but they tended to have higher scores than young adults (Konrad et al., 2005). In this current study, we had no evidence of the improvement of alerting effect from late childhood to adulthood, but a slow and progressive development of the alerting effect can be possible (Pozuelos et al., 2014). Indeed, we found an improvement of alerting effect in older children regardless of their group (intellectually gifted or average children). On the orienting effect, the IGC seem to have the same efficiency as the IAC to disengage and to engage again the attention focus towards a salient stimulus. We did not observe an increase in the orienting performance after the late childhood (Lewis et al., 2016; Mullane et al., 2016; Rueda et al., 2004). In contrast, we found a significant difference between both the children's groups and the young adults in the orienting effect. Thus, the orienting network seems to improve after adolescence (Konrad et al., 2004; Pozuelos et al., 2014; Waszak, Li, & Hommel, 2010). The orienting network would have critical periods of its development before the age of 6 years old (Pozuelos et al., 2014; Rueda et al., 2004) and after the age of 14 years old. On the executive control effect, we have an additional evidence that the IGC have better performance than the IAC (Calero et al., 2007; Duan et al., 2009; Johnson et al., 2003; Liu et al., 2011; 2011b). Our results showed the IGC had better efficiency than their pairs, to focus volitionally in order to solve a simple conflict. This study indicated no significant decrease in the control executive score from 8 to 14 years

old. So, there is the stabilization of the control executive effect during this period (Lewis et al., 2016; Mullane et al., 2016; Pozuelos et al., 2014; Rueda et al., 2004). Nevertheless, both children groups differed from the young adults in executive control indicating an enhancement of this attentional system through adulthood (Konrad et al., 2005; Lewis et al., 2016; Pozuelos et al., 2014; Rueda et al., 2004). Our findings support the idea that the control executive has critical periods during its development (Lewis et al., 2016). In literature, executive control is considered as important in the functioning of working memory, naming the capacity to process, to manipulate and to storage briefly information during a cognitive activity (Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Bleckley, Conway, & Engle, 2001). This cognitive ability has strongly related to the intellectual capacities (Ackerman, Beier, & Boyle, 2005). Some studies have highlighted IGC have higher performance in working memory than IAC (Calero et al., 2007; Hoard, Geary, Byrd-Craven, & Nugent, 2008; Leikin, Paz-Baruch, & Leikin, 2013; van Viersen, Kroesbergen, Slot, & de Bree, 2014). Future investigations might explore the relationship between working memory capacity and executive control in IGC.

Limitations of the Study

This study is focused on the cross-sectional developmental trajectories of the attentional networks in IGC from late childhood to early adolescence. In typical development, these attentional network begins to enhance from early childhood and their enhancement decreases in late childhood (Mezzacappa, 2004; Rueda et al., 2004; Pozuelos et al., 2014). During the early childhood, we have no information about the rate of developmental trajectory of the attentional networks, particularly about the executive control performance, in IGC. There is a strong limitation in the identification of a highly intellectual potential before school age. The intellectual capacities seem to be more stable around 7

years-old (Schneider, Niklas, & Schmiedeler, 2014). So, the identification of the high intellectual potential before the scholar age would be very probabilistic. Longitudinal studies could pass this issue and allowing us to better understand the rate of the development of these attentional networks in IGC during these critical periods.

The child version of ANT was used to estimate the efficiency of each attentional network (Rueda et al., 2004). This task used only the spatially valid cue to assess the orienting effect. The use of invalid and valid cue can increase the orienting effect and to improve the observation of the development of orienting networks with the age (Abundis-Gutiérrez, Checa, Castellanos, & Rueda, 2014; Waszak et al., 2010).

In the current study, the design of this version of the ANT could not investigate the interaction between the attentional networks. In literature, some studies showed the presence of interactions between the attentional networks (Callejas, Lupiáñez, Funes, & Tudela, 2005; Pozuelos et al., 2014). These interactions modulate the efficiency of each attentional network, and the effect of this modulation is influenced by the child development (Mullane et al., 2016; Pozuelos et al., 2014). A modified ANT was created to investigate specifically these interactions (see Callejas, Lupiáñez, & Tudela, 2004 for details). In the future studies, the investigation of the interaction between networks can bring another perspective about the attentional development in IGC.

Despite being fun and game-like, the child version of ANT becomes quickly boredom for children (Ishigami & Klein, 2015), along with young adults. Boredom might affect the participant's engagement on the attentional task. Thus, the participant's performance could be underestimated in all conditions of this type of task. Some authors shown that it was possible to make a game-like tool assessing the attentional networks more engaging than the ANT (e.g. Klein, Hassan, Wilson, Ishigami, & Mulle, 2017).

Conclusion

The current study is investigated the development of alerting, orienting and executive control networks in IGC. From late childhood to middle adolescence, our analyses indicate that the gradient of the development of each attentional networks in IGC does not distinguish from those of IAC. However, IGC have higher executive control performance than IAC. In literature, executive control plays a crucial role in the functioning of the working memory i.e., the capacity to process, to manipulate and to store briefly information in the current cognitive activity (Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Bleckley, Conway, & Engle, 2001), and the intellectual functioning (Cowan et al., 2006). Thus, our finding confirms the executive control is an important cognitive characteristic in IGC. This characteristic has implications in education.

The executive control has a mediator role between student's adjustment to school environment and academic achievement (Checa, Rodríguez-Bailón, Rueda, 2008). IGC are more accurate in executive control, which can explain their better reasoning abilities (Rueda, Rothbart, McCandliss, Saccomanno, Posner, 2005). They may need fewer steps to acquire the school knowledge. The findings of the current paper support the importance to adapt the school curriculum of IGC, such as enrichment programs or accelerated education.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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